GUIDE TO THE PRACTICAL ELEMENTS OF ELECTRICAL TESTING

By J. Warren

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PREFACE.

In the following descriptive series the writer does not purpose setting down original ideas on the above subject, but aims rather at a compilation of the most useful electrical tests and the manner in which they may be practically conducted, together with a summary description of the principal apparatus involved, on the lines of such a popular work as Kempe's "Handbook of Electrical Testing;" but, contrary to the general rule in the above and similar text-books, eschewing all mention of the theory underlying the various processes therein described, which, although a necessary adjunct to the training of the electrical engineer proper, is, nevertheless, somewhat of a hindrance when prompt reference to the manner of conducting a certain test is necessary.

For theoretical considerations on the following paragraphs the reader is therefore referred to Kempe's "Handbook" and kindred works. The diagrams and blocks illustrating the text have, in all cases, been rendered in as clear and comprehensive a form as possible, the usual symbols being employed to represent batteries, keys, etc., a rudimentary knowledge of electrical principles being necessarily assumed on the part of the reader.

The author begs to tender his sincere thanks to Messrs. Nalder Bros., Elliott Bros., J. Pitkin, R. Paul, Evershed and Vignoles, Cowans, the India Rubber, Gutta Percha, and Telegraph Works Company, and James White, for the loan of the major portion of the blocks illustrating the pages to follow. His thanks are also due to the publishers

who have been indefatigable in their efforts to assist in the compilation.

In concluding the series, the writer ventures to hope that its contents will prove of practical utility to the practical man, for whom they are mainly written, and that their present compilation in book form will serve to fill a vacant space in the library of such members of the electrical profession as require a brief but practical treatise on the various methods and applications of electrical testing, without the concomitant theoretical and mathematical proofs which usually accompany kindred works on the subject.

Great care has been exercised in the compilation of this series to render all formulæ, etc., correctly, and the author will esteem it a favour if those of his readers who may note errors in the subsequent context will, by drawing his attention thereto as promptly as possible, assist in the eradication of such errors from future issues.

J. WARREN.

CONTENTS.

THE PRACTICAL ELEMENTS OF ELECTRICAL TESTING.

INSTRUMENTS AND APPARATUS.

Galvanometers.—The most essential unit in an electrical testing outfit of almost any description is undoubtedly the galvanometer, an instrument which is constructed in many varied forms, and whose indications, modified by the local conditions under which it is working, are taken as visible records of the results of the experiment or test in which it performs its office.

The principle underlying the action of all galvanometers is as follows:—A magnetic needle, N S, Fig. 1, is suitably supported at the centre of a coil, *a b*, which may consist

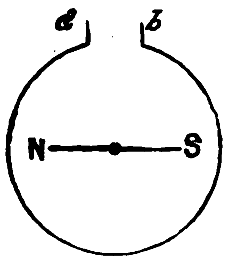


FIG. 1.

of one or many turns of wire, in such a manner that, when in its normal condition, *i.e.*, when in the earth's magnetic meridian, it assumes the condition shown in the figure, it lies in a plane with the coil. If, however, an electric current be passed round the coil *a b* in either direction, the needle, N S, following a well-known law, tends to set itself at right angles to the plane of the coil, and the measure of this tendency, as indicated by suitable means,

is an indication of the current passing through the coil *a b*, either directly or indirectly, according to the secondary principles of the particular form of galvanometer under consideration. In some types the action is reversed, the needle (in the form of a permanent magnet or otherwise) being fixed and the coil movable, but, in either case, the fundamental principle remains the same.

One of the simplest types of galvanometer used in practical testing, and that only for very rough indications of the existence of a current, as in simple continuity tests, for example, is the ordinary linesman's "detector," which is made up very simply with a view to portability and rough handling.

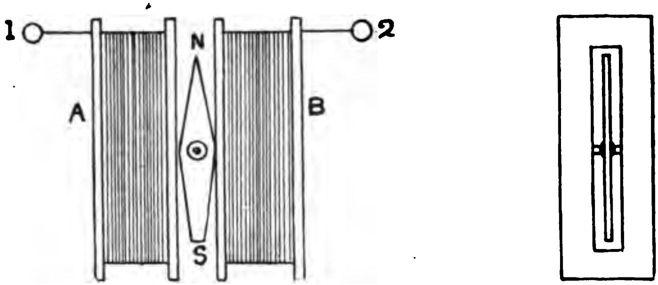


FIG. 2.

Linesman's Detector Galvanometer, by the India Rubber, Gutta-Percha, and Telegraph Works Co., Ltd., Silvertown.

Fig. 2 represents diagrammatically its internal construction.

A and B are two equal coils of wire wound in the same direction, to a resistance of about 50 ohms apiece, or 100 ohms in all, on hollow bobbins, or "formers," mounted on a suitable base plate, and enclosing between them a magnetic needle, N S, mounted on a delicately-pivoted horizontal axis. The needle, N S, is made slightly heavier at its (S) extremity, in order that it may, by force of gravity, always remain in the vertical position when when no current passes through the coils A B. The two coils are connected together, and their free extremities led out to suitable terminals, 1 and 2, on the exterior of the case, which is usually of wood. Attached to the horizontal axis in a plane with the needle N S is a pointer or index, not shown in the figure, which indicates the movements of N S consequent upon the passage of a current, upon an engraved dial plate mounted behind a protecting glass front, in one of the sides of the case.

Such an instrument as that described above, although somewhat crude, is nevertheless of great use in ordinary workshop tests, and is principally employed, as its name implies, by telegraph and telephone linesmen for testing the continuity of circuits and similar purposes. At best it is only on indicator.

A similar instrument of a slightly more sensitive type, in which the needle is pivoted horizontally instead of vertically, and which is mounted in a circular metal case with a glass top, is shown in the accompanying illustration. It is wound to a higher resistance than the foregoing, and

Portable Galvanometer, about 1,000ω, by Nalder Bros. & Co.

is fitted in a leather case with accompanying shoulder-strap for the sake of portability.

The Tangent Galvanometer.—This galvanometer, though a very familiar one in text-book practice, is seldom used in general electric testing. It is, however,

largely adopted in the Telegraph Department of the G.P.O. for testing purposes, and the standard Post Office pattern, as manufactured by Messrs. Elliott Bros., is depicted in the accompanying illustration.

In its simplest form it consists of a circular vertical coil A, Fig. 3, surrounding a delicately pivoted magnetic needle N S placed at the centre, and capable of motion in a horizontal plane. The needle N S must be very short (some ½ in. to ¾ in. for a 6-in. coil), as,

theoretically, it stands in the place of a point pole, and, in consequence, if too long, erroneous results will be obtained. It depends in principle on the fact that the "strength of currents circulating in the coil are directly proportional to the tangents of the angles of deflection of the needle."

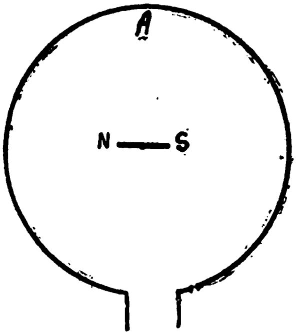


FIG. 3.

An index finger is attached to the needle or pivot, and the scale is divided up into tangents; 45 degs. is the angle of maximum sensitiveness of this instrument, and it is therefore advisable, wherever possible, to obtain a deflection as near this value as possible.

The Post Office form of tangent galvanometer illustrated above is wound differentially, its respective windings having a resistance of 160 ohms apiece. The extremities of these windings are brought to the four terminals shown on the base, so that they can be connected in any desired manner. In addition to the above, seven shunts, having the respective values of 1-5th, 1-10th, 1-20th, 1-40th, 1-80th, 1-160th, and 1-320th, are fitted in the base of the instrument and connected to the multiple plug switch. Their terminals are connected to the outer terminals of the galvanometer winding, so that they can be connected across the two 160-ohm coils in series by depressing the key shown in the figure. When inserted in the order mentioned above, they reduce the sensitiveness of the instrument in direct proportion, and the ohmic resistances between the outside terminals from an original total of 320 ohms to 32, 16, 8, 4, 2, 1, and $\frac{1}{2}$ ohm respectively.

We pass on now to a much more sensitive type of instrument, to wit, the reflecting galvanometer, the general construction of which, in its simplest form, is roughly indicated in Fig. 4, where *a b* represents the coil as before.

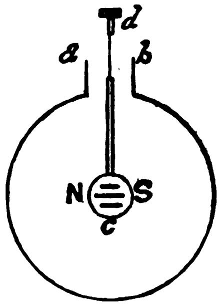


FIG. 4.

The needle, N S, in this case takes the form of a short strip, or series of strips, of magnetised watch-spring, attached, with their like poles together, to the back of a small circular mirror, *c*, about ½ in. in diameter, by means of a suitable cement, such as shellac or beeswax (the latter is unsuitable if the instrument be intended for use in a warm room). The mirror is carried by a short vertical aluminium wire supported at its upper extremity from a single fibre of unspun cocoon silk which has been previously treated to remove all twists and kinks, and is in turn attached at its upper extremity to a stud or screw, *d*, fitted in the body of the instrument, and by means of which it can be raised or lowered in order to bring it to the centre of the coil. The complete instrument, in its practical form, is shown in the block below. In this case no actual index is attached to the moving system, its place being filled by a beam of light from a suitable source such as an oil lamp, or, better still, one of the electric incandescent variety, which is thrown on to the mirror *c* and reflected back on to a transparent scale, such as that illustrated below, the requisite definition being rendered by a black line in the shape of a fine blackened wire or hair stretched across the aperture of emission, and the indications being taken from the coincidence of this line with those of the divisions on the scale.

It will be seen from the above description that a much more sensitive indication is recorded by this type of instrument, in that the support for the moving system is frictionless, and the range of the index only limited by the confines of space and the intensity of the reflected beam of light.

Thomson Tripod Galvanometer, by Elliott Bros.

In order to render this instrument independent of the earth's magnetism, and consequently more sensitive still, it has been constructed in "astatic" form, as indicated in Fig. 5, where *a b* and *e f* represent two coils, so connected as to exercise a similar comboned influence upon the system of magnets N S, which is doubled in this type of instrument, one set being attached as before to the back of the mirror *c*, and the other, an equal and similar set, with their N and S poles in an exactly opposite direction to those of the foregoing are attached at a negligible distance

below, to the face of a small aluminium vane, g, which oscillates with the mirror and aluminium wire support, and

Lamp Stand, with Transparent Galvanometer Scale, by Nalder Bros.

is closely surrounded by a small similarly-shaped chamber, closed, or nearly closed, on all sides, the interior surfaces

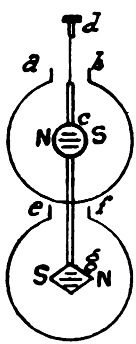


FIG. 5.

of which only just clear the edges of the vane *g*. This latter device constitutes what is known as a "damping" box, *i.e.*, it "damps" or deadens the otherwise irresponsible oscillations of the suspended system, and reduces them to a series of steady and regular swings with a definite period, a result which renders the reading of the resultant deflections on the scale a much less arduous task than would otherwise be the case. This effect is the result of a small enclosed volume of air in the surrounding chamber which renders any rapid movement of the vane *g* an absolute impossibility under the circumstances. The device may be rendered adjustable by mounting the front wall of the damping chamber on a movable slide, by which means it can be adjusted with regard to its distance from the other walls of the chamber; by this means any requisite degree of exit for the otherwise enclosed air may be obtained, and the consequent damping effect on the system regulated accordingly.

The usual procedure in constructing an instrument of the latter type is to arrange the two sets of coils *a b* and *e f* in pairs, making four in all, the eight extremities of which are brought to terminals on the exterior of the base, and can be connected up as desired, in order to vary the total resistance of the instrument windings for various purposes, or to render it available for use "differentially."

The coils are mounted on metal frames, hinged to the main vertical supports of the galvanometer, so that they can be turned back out of the way in the event of any necessary repairs to the suspended system, such as that caused by the breaking of a silk fibre, etc.

The term "differentially," which was employed in the preceding paragraph, requires some explanation. Referring back to Fig. 5, it will be recognised, from what has gone before, that if equal and similar currents be simultaneously passed round the two coils *a b* and *e f* in the same direction, *i.e.*, from *a* to *b* and from *e* to *f* their respective effects upon the two magnetic systems N S will neutralise one another, and no movement of the system will take place. If, however, the current through one of the coils preponderates slightly over that through the other, a slight movement, due to the excess of current, will result, and it will ultimately be shown how, by connecting one coil in a certain circuit and another in a different part of the

same or similar circuits, this fact is utilised in certain tests, the system thus made use of being termed differential.

Lord Kelvin's High-Resistance Four-Coil Galvanometer, by Nalder Bros.

Reverting to the original theme, we now come to a consideration of that class of instrument known as "dead-beat," *i.e.*, those which record their indications directly, without any concomitant oscillation above or below the resultant division on the scale. Of this class, the d'Arsonval galvanometer, illustrated in the accompanying block, was the pioneer. It is constructed on the moving coil principle previously referred to, the magnet (permanent) being fixed, and the coil suspended; for this reason it is necessarily less sensitive than the foregoing types of reflecting galvanometer, in which the simple magnetic needle constitutes the moving unit, but this comparatively small disadvantage is amply compensated for by the attendant advantages offered by its dead-beat qualities,

especially when, as is very often the case, time is an object while conducting certain tests.

D'Arsonval Type Reflecting Galvanometer, by Nalder Bros.

Fig. 6 illustrates roughly the detailed construction of the d'Arsonval galvanometer depicted *in toto* in the above

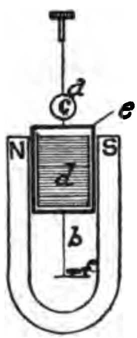


FIG. 6.

illustration. N S is a set of three strong permanent magnets, bolted with their like poles together. *a* and *b* are fine silver suspension wires, leading the current to, and, at the same time, acting in the capacity previously filled by

the single silk fibre, to the coil *e*, which is extremely light and is wound on a closed metal frame of very thin silver or copper, the induced currents in which, set up by the originating current through the coil *e*, exercise a reactive effect upon the system, and cause it to rapidly assume a position of rest after having been set in motion by the original current previously referred to, or, in other words, the current which the instrument is required to indicate. *c* is the attached mirror as before, whilst *d* is a second permanent magnet cylindrical in shape, and constructed of horizontal laminæ. It is arranged with its North pole opposite the South pole of the original horse-shoe magnet N S, and, by this means, a very intense magnetic field is set up in the small space between the two magnets, which space is occupied with just sufficient turning clearance by the suspended coil *e*. *f* is a small spring with adjusting-screw, to which the lower suspension wire *b* is attached, and the moving system thus maintained in sufficient tension to produce equilibrium, and at the same time freedom of motion for the working coil. The ordinary patterns of this type of instrument are wound to varying resistances from 150 to 750 ohms, according to the purpose for which they are ultimately required.

The following brief description of one or two of the leading types of this instrument which are at present on the market will perhaps assist the reader in his choice of an instrument suited to the special requirements of any tests which he may be called upon to perform by its aid.

The practical working principle of the D'Arsonval galvanometer pure and simple has already been dealt with (see Fig. 6 and accompanying illustration), so that I shall not touch further upon it at this point, but proceed to deal instead with some of the more important details which occur in connection with the various patterns of instrument to be described.

The illustration accompanying Fig. 6 of this series represents the form of D'Arsonval galvanometer manufactured and sold by Messrs. Nalder Bros. and Co., of Westminster, and it is supplied either "damped" or "undamped," as required—*i.e.*, it may be either dead beat or ballistic.

For the benefit of the uninitiated, I may here state that the damping or dead beat properties in a D'Arsonval

galvanometer are, unlike those in the Thomson type, obtained by a special feature in the construction of the suspended coil. The latter, where thorough damping is required, is wound on a complete metal frame or "former" of silver or aluminium, and the induced currents set up in the frame itself by its movement in the permanent magnetic field serve to check its oscillations, and cause the system to more rapidly assume the zero position, after having been deflected therefrom by the passage of a current through its coil. In the undamped form this frame or former is either divided at one point so as not to form a complete circuit, or is constructed of some non-conducting material such as ivory.

Messrs. Nalder Bros. have adopted 1-40th of an inch as the width of their standard scale division, instead of one millimetre, as is usual in such cases, their contention being that this dimension is a more convenient one for the purpose.

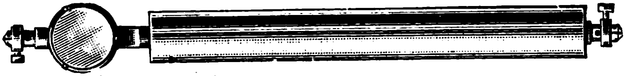
The "Figure of Merit" in their list is reckoned in megohms, *i.e.*, the number of megohms through which an E.M.F. of one volt at the terminals of the instrument will produce a deflection of one scale division (1-40th inch), and the following particulars, excerpted from their list, apply to the various grades of this instrument supplied by them:—

List No.	Figure of Merit.	Remarks.
G250	150 Megohms	Damped
G251	150 "	Undamped
G253	1,000 "	Damped
G254	1,000 "	Undamped
G256	2,000 "	Damped
G257	2,000 "	Undamped

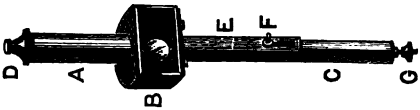
Mr. Robert W. Paul, of 68, High Molborn, supplies the well-known Ayrton-Mather form of D'Arsonval galvanometer, which is depicted in the accompanying illustration, and is a very compact and useful form of instrument, occupying only some 7 ins. by 7 ins. by 8 ins. of space when packed in case complete for transit. It is supplied either in dead beat or ballistic form, as required, and can be obtained wound to any resistance from 5 to 1,000 ohms, the stock pattern having a resistance of some 325 ohms.

The salient feature, or suspended coil, of the instrument is self-contained, being constructed with a sur-

rounding and protecting tube, which slides into attachments on the main body of the instrument, making contact simultaneously with the terminals thereof. These slides are complete in themselves, and are interchangeable, so that a single instrument may be supplied with a comprehensive set of slides which will conform to a multiplicity of requirements. One of these detachable slides is depicted below, both *in toto* and with the inner coil tube removed and shown separately.



Coil Tube of Ayrton-Mather Galvanometer.



Coil Tube in Slide.

As mentioned above, the resistance of the stock pattern is 325 ohms wound in copper, although a winding of other material will be substituted if desired, and its *constant* is 20 millimetre scale divisions per microampère with a scale range of one metre.

New Model. Ayrton-Mather Galvanometer, by Paul.

The period of swing of the dead beat form is two seconds, and of the ballistic five seconds.

The accompanying illustration represents the *New Model* of this type of instrument, specially designed with a view to complete accessibility of working parts for laboratory use.

Mr. James Pitkin, of Clerkenwell, supplies a cheap form of the Holden-D'Arsonval galvanometer, which is an improved form of dead beat instrument designed by Major Holden, R.A. It is depicted below with the case removed, and, as regards its detailed construction, I cannot do better than quote its description as issued in brief pamphlet form by the maker:—

"The success which has attended the introduction of the Holden-D'Arsonval galvanometer in 1887 has led the inventor, Major Holden, R.A., to turn his attention to an instrument which, while being of such a price as to be within the reach of students and others requiring a galvanometer of the reflecting type, should yet have *many*

Holden-D'Arsonval Galvanometer, by Pitkin.

of the advantages of the more expensive form. The engraving shows the instrument, which is about 8 ins. high, with the cover removed, revealing the interior. The base is a brass casting, into which the levelling screws turn. This casting carries on the upper surface the

stamped steel magnets, which produce the field in which the coil moves, and it also carries the tubular socket into which a frame carrying the suspended coil fits. The removable frame forms one of the features of this galvanometer, as it enables the coil to be changed instantly with the greatest ease, so that the galvanometer may be used for measurement of the smallest currents, from one-millionth of an ampère to 1,000 ampères, either with continuous or alternating current, without removing it from the testing table.

"The frame consists of two parts, insulated from one another, the lower being, when in position, in contact with the base of the instrument. The coil is suspended from a torsion head at the top to a tension spring below. The soft iron core, around which the coil moves, is attached to a cylindrical plug on the frame, which fixes into the socket before mentioned. A flexible wire connects the upper insulated portion of the frame with one terminal, the other being in contact with the base. Different descriptions of frames are supplied. For instance, for zero testing there is one of 500 turns, of about 500 ohms resistance, while for measuring ampères, with the instrument shunted by means of a platinoid or manganin strip, the coil is wound with only 10 turns of the same material as the strip is composed of, and will give a deflection over the whole of its scale with .002 ampère; then to measure, say, 100 volts with the above coil, resistance of 50,000 ohms is provided, wound on two bobbins, each being 25,000 ohms; so that by using the two in series the instrument is suitable for measuring 100 volts; with one in series, 50 volts; with two in parallel, 25 volts. There is no temperature allowance, owing to the extremely small current and to the materials used.

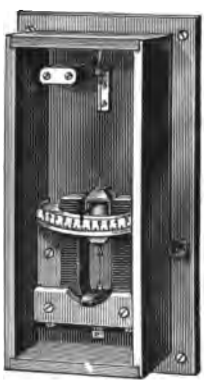
"Another frame for the measurement of alternate currents is based on the expansion of a wire under the heating influence produced by a current passing through it. This form is most useful for measuring voltages with an added non-inductive resistance of about 150 ohms per volt to be measured. As regards figure of merit, one volt through one megohm gives a deflection of 10 millimetres, using the 500 turn coil at a distance of two metres from the screen. When required. the

instrument can be made more portable by means of a patented clip, fitted to the coils, so that the coil may be firmly fixed without loosening or slackening the suspension, thus enabling them to be subjected to the roughest usage, and even sent by post without fear of breakage."

The above instrument is also constructed in a somewhat more elaborate form, under the name of the Holden-D'Arsonval Universal Reflecting Galvanometer. The principle of this instrument is precisely similar to that described above, the only difference being that it is somewhat more sensitive, and commands, in consequence, a slightly higher market value. The standard pattern is provided with four interchangeable coils and frames, viz.:—(1) A coil of 500 turns with a resistance of 600 ohms; (2) A coil of 250 turns and 265 ohms; (3) A coil of 125 turns and 133 ohms; (4) A coil of 250 turns and 70 ohms resistance.

The constant for the 500 turn coil is ten millimetre scale divisions with an E.M.F. of one volt through ten megohms, the length of the scale range being two metres.

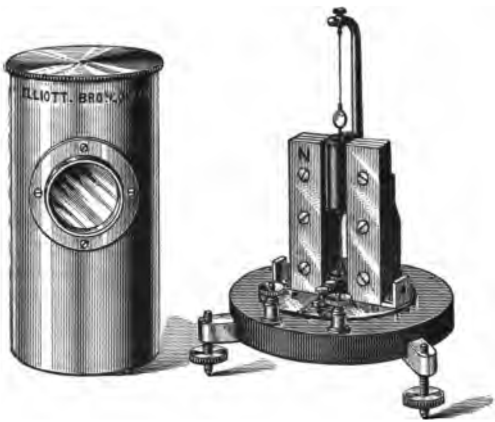
We now come to the productions of Messrs. Elliott Bros., which are of various types, calculated to meet a variety of requirements. The simplest and cheapest form of D'Arsonval galvanometer manufactured by this well-known firm is illustrated below, and consists of a simple suspended coil and permanent magnet mounted in an



D'Arsonval Galvanometer, by Elliott Bros.

oblong wooden case, with a glass front. It is intended for workshop or similar use, where approximate results only are needed, and to that end is provided with a pointer or index in addition to a mirror, the said index travelling over a vertical semicircular scale. An appreciable deflection of the index is obtained with a current of 1.6×10^{6} ampère, passing through the suspended coil.

Their next simplest form is illustrated below, and is very similar to that of Messrs. Nalder Bros., which has been already described and illustrated. It consists of the usual vertical horseshoe magnet, between the upturned poles of which is suspended the coil, which may be of any resistance from 10 to 1,000 ohms, according to the requirements of the customer. The suspensions consist



D'Arsonval Galvanometer, by Elliott Bros.

of fine phosphor bronze strips above and below the coil; a plane or focus mirror is provided, and the instrument is mounted on a mahogany base fitted with the usual levelling screws and provided with the cylindrical brass cover shown in the illustration.

A somewhat more elaborate type of instrument is provided in Professor Rowland's form of D'Arsonval galvanometer, which is shown in the accompanying illustration. This instrument is more sensitive than the foregoing types in that it possesses a somewhat longer suspension. It is

provided with a lifting attachment to receive the weight of the coil, and so protect the suspension from injury when the instrument is packed for transit. At a scale

D'Arsonval Galvanometer (Rowland's), by Elliott Bros.

range of one metre this instrument has a constant of one millimetre scale division, with a deflective current of 1×10^{-8} ampère through its coil.

Another type of D'Arsonval galvanometer manufactured

by Messrs. Elliott Bros. for cable testing work is depicted in the accompanying illustration. It consists of a substantial metal frame, mounted on a broad base, with or without levelling screws (they are shown in the figure). The moving coil is mounted in a separate frame supported by the poles of the magnet and removable therefrom. The suspensions consist of a fine strip above and a spiral strip below, giving greater sensibility; the connecting wires to the top and bottom suspensions are secured with good electrical contact by screws, and are easily detachable when it is desired to remove the frame carrying the suspension. Spare suspended coils of varying resistances may be obtained for this instrument, in frames complete, and are easily placed in position, being interchangeable; the ordinary stock pattern has a resistance of 1,000 ohms.

A feature of this instrument lies in the small glass window provided in the front of the case for the passage of the beam of light to and from the mirror. This window, as will be seen in the figure, is given a slight upward tilt, such that the light reflected from the surface of the glass itself shall not, as it frequently does in the ordinary form of vertical window, interfere with the actual reflected beam, and so destroy the definition of the image due to the latter.

Still another type of D'Arsonval instrument, complete with scale, is manufactured by this firm, and is also illustrated. It is designed with a view to portability, and to that end, the usual form of scale and lamp is dispensed with, being replaced by the form of scale shown, in which the deflections are read through the sighting hole just above the scale. The device is sensitive and self-contained, and can be fixed either against a vertical support or on a horizontal table or basis as required.

Besides the dead-beat properties already alluded to, D'Arsonval galvanometers also possess the additional advantage of being uninfluenced by the proximity of masses of magnetic material, such as dynamos, etc., which renders them eminently suitable for engine-room work and similar purposes involving the neighbourhood of otherwise disturbing influences.

Whilst on the subject of magnetic disturbances, the writer will proceed to deal briefly with the systems of magnetic control and shielding adopted when using the

ordinary type of reflecting galvanometer amid disturbing surroundings.

D'Arsonval Galvanometer, by Elliott Bros.

D'Arsonval Galvanometer, by Elliott Bros.

Referring to previous illustrations, it will be noticed that the instruments in question are provided with an ordinary bar magnet fitted to, and capable of adjustment on, a vertical stem rising from the centre of the upper portion of the galvanometer case. This bar magnet performs a useful office, in that it serves, when properly adjusted, to counteract any effects upon the needle, due to the earth's magnetic field; the sensibility of the instrument is, in act, to a considerable extent, controlled by it. If the magnet be so placed as to approximate as nearly as possible to the suspended magnets inside the case, it will exercise a considerable influence upon them, and their sensibility to motion under the influence of a current passing round the coils will in consequence be diminished. If, on the other hand, the magnet be adjusted at the opposite extremity of the supporting stem, the earth's magnetism (in the case of single-needle instruments) comes into play, and the galvanometer must, in consequence, be placed with its needles in the magnetic meridian, a condition of things not altogether convenient. In order to procure the best possible conditions for working, the controlling magnet should, by dint of experiment, be so adjusted that its magnetic field just overcomes that due to the earth; when this is the case, the suspended system can be brought to zero by gently turning the magnet in the required direction, whilst still in the same horizontal plane, *i.e.*, without altering its vertical position on the supporting stem, an operation facilitated in modern types by the addition of a milled screw and pinion.

As regards magnetic shielding; in cases where it is necessary to employ a reflecting galvanometer of the first type in the neighbourhood of masses of magnetic material, it must be shielded from disturbing influences by the addition of a surrounding iron case, which need not be of excessive thickness, from ½ in. to ¾ in. being ample under ordinary circumstances. An oblong opening closed by a thin sheet of glass, or, better still, clear mica, is provided in the surrounding shield for the passage of the beam of light, and the ordinary simple controlling magnet is replaced by two equal magnets mounted on separate telescopic and insulating axes in the interior of the case, either above or below the needles, controlled by convenient milled heads or turning-screws on the exterior. By approaching

or receding the like poles of these magnets to or from one another, the resultant field is increased or diminished, and its consequent controlling effect upon the needles thereby adjusted. Needless to state the iron case must be free from magnetism in itself. Where a solid iron case is not available, a hollow shell filled with iron filings answers the same purpose, and is, with a little ingenuity, easily constructed.

These systems of magnetic control and shielding are not, of course, necessary with the moving coil type, which instruments are immune from external magnetic influences.

The Electrometer.—An electrometer is essentially an instrument for measuring or comparing difference of potential by the applied principles of electrostatic attraction and repulsion; and, further, its action is amenable to the same laws which control the latter properties.

An absolute electrometer is one which records its measurements directly in absolute units without the necessity for comparison with measurements taken in another apparatus, or, in other words, the results obtained on it are in terms of other known units, such as the physical reactions of springs and torsional wires.

A B, and C D, Fig. 7, represent two parallel plates separated by a distance a, which is neglibly small in comparison with any plane dimension of the plates. Such an arrangement of parallel plates with a separate portion in the centre of one of them, A B, is met with in the case of the "attracted disc" electrometers with what is known as the "guard-ring," corresponding to that portion of the disc A B surrounding its central area.

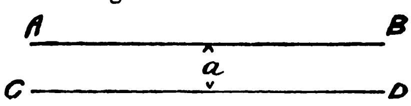


Fig. 7.

Sir William Thomson, who has designed almost all the electrometers adopted for present-day use, has divided them under three heads, viz.: (1) Repulsion Electrometers, such as the original torsion balance of Coulomb; (2) Attracted Disc Electrometers, exampled in the Snow-Harris, Thomson's Absolute and Long Range Electrometers; and (3) Symmetrical Electrometers, to which

belongs the well-known and widely adopted Thomson Quadrant Electrometer, so called from the form of its conductors. I shall not attempt to deal with all the above-mentioned types of instrument, but shall select as my model that popular and widely adopted specimen of the Symmetrical class known as the Quadrant-Electrometer. It was evolved, from a primary contrivance known as the divided ring instrument, the principle of which is diagrammatically represented in Fig. 8, where A, B, represent two flat semi-circular strips of metal separated at their two extremities by a small insulating gap. Passing through the centre of the circle enclosed by these strips was a vertical suspension wire, carrying on one side of it, and at right angles to itself, a light needle C. It is obvious that if this needle be charged with electricity of a certain sign, say positive, and so insulated that its potential remains constant, and also if the two strips A and B be charged with positive and negative electricity respectively, the one will repel and the other attract the needle C, and the force of that attraction and repulsion, as measured by a torsion head

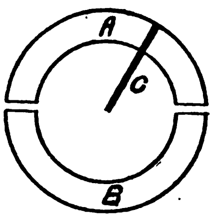


FIG. 8.

acting on the suspension wire, will be an indication of the difference of potential between the semi-circular strips A B.

In the quadrant electrometer the semi-circles developed into four box quadrants A, B, C, D, Fig. 9, of which the opposite quadrants A, B, and C, D, are respectively connected together. The needle is also made symmetrical about its axis, and takes the form shown by the dotted lines in Fig. 9, which is a plan and elevation of the needle and quadrants as normally arranged. The quadrants themselves are mounted on insulating stems suspended from the cover, one of them being so arranged

as to be adjustable micrometrically. The needle, which is of thin sheet aluminium, is mounted horizontally on the vertical suspension wire which ends at its upper ex-

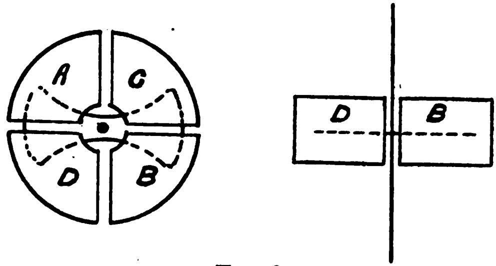
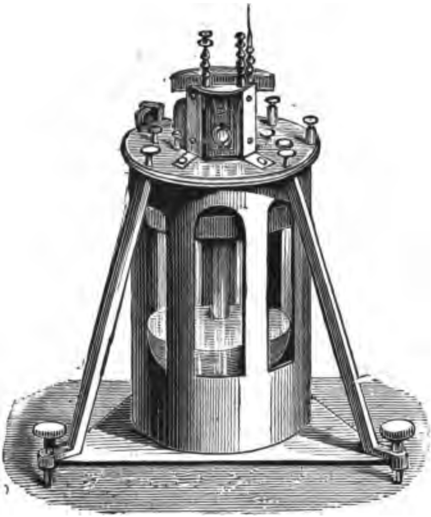


FIG. 9.

tremity in a small cross-bar, to the two equi-distant extremities of which is attached the bifiliar suspension; just below the cross-bar is attached a concave mirror protected from external influences by a split tube. At its lower extremity the suspension wire ends in a small platinum weight, suspended in sulphuric acid which has been boiled with sulphate of ammonia to expel deleterious impurities, and thus exercises a damping effect upon the suspended system. The bifiliar suspension is attached to an arrangement of screws and springs permitting of all the necessary adjustments for azimuth, equality of suspensory length, etc. The outside coating of the glass case, which takes the form of an inverted bell jar, is constituted by strips of tinfoil pasted on it, whilst the inside coating is represented by the sulphuric acid, which also serves to keep the interior of the apparatus free from moisture. The platinum weight at the lower extremity of the suspension wire is submerged, as before mentioned, in the sulphuric acid, and thus connects the needle with the interior coating, whilst the quadrants are provided with suitable electrodes for connecting them either with the case, or the body under test at will.

The mirror and suspension adjustments are enclosed by a protecting cover, known as the "lantern," in the side of which an opening is left, closed by a glass window, to permit of the mirror being used as in an ordinary reflecting galvanometer with lamp and scale. The instru-

ment is provided with a gauge and replenisher, whilst the suspension wire is protected from external influences by an encircling guard-tube connected to the acid by a platinum wire at its lower extremity.



Sir Wm. Thomson's (Lord Kelvin) Quadrant Electrometer.

An induction plate, or sheet of metal slightly smaller in area than the upper surface of one of the quadrants, but of similar shape, is supported from the lid of the instrument by an insulating glass stem, and is provided with a terminal or electrode communicating with the exterior.

As the instructions for setting up the quadrant electrometer vary slightly with certain variations in the details which have been made from time to time, and are supplied with the instrument, the writer does not consider it necessary to repeat them here, but will proceed at once with a description of the method of using the instrument.

To charge the containing jar, the main electrodes and the induction plate, together with a binding screw on the cover, are electrically connected together, and the charge imparted by a small electrophorous supplied with the electrometer, to the charging electrode or terminal, being

subsequently adjusted to the requisite normal as indicated on the gauge, by means of a replenisher.

Under normal circumstances leakage of charge is inappreciable, causing, so to speak, a hair-breadth variation in the gauge indication per 24 hours, and may be restored by the replenisher. Should the leakage prove excessive, however, proceedings must at once be taken to eliminate it. To this end, the glass insulating stems should be well washed with a piece of hard silk ribbon dipped in soap and water, being subsequently rinsed to remove the soap, and finally dried by friction with a dry piece of the same ribbon. Similarly, the various parts should be dusted with a fine camel-hair brush, and the glass jar itself, in the event of any accidental splashing of the acid, well washed and dried. The sole plate of the replenisher, a frequent source of leakage, can be treated by removal and immersion in boiling water, followed by a subsequent drying and the application to its surface of a paraffine film. Similar treatment is suitable for other ebonite fittings, such as the supports for the electrodes.

Although there are, of course, a large number of instruments other than those described in the preceding paragraphs under the heading of galvanometers, the types thus enumerated will be ample for the tests to be described in the following pages; and this being the case, the writer will not risk confusing the minds of his readers by entering into the details of other patterns.

Shunts.—In utilising some of the more delicate types of galvanometer just described, it will be obvious that the passage of a current of too great magnitude through the winding would tend to produce a somewhat violent throw or deflection of the moving system, which would, besides having an injurious effect upon the delicate suspensions, be unreadable, owing to its indications extending beyond the extreme limits of the scale. In order, therefore, to bring such abnormal currents within the practical working range of the instruments in question, it is necessary to adopt some method by means of which their ultimate effects upon the suspended system can be materially reduced, and this object is attained by the use of what are technically known as "shunts."

Referring to Fig. 10, if G be a galvanometer, through the coils of which is passed a current of electricity by way of

the leading wires *a b*, it follows from the laws governing multiple circuits that if we connect a resistance S across *a* and *b* at a point between the source of current and the

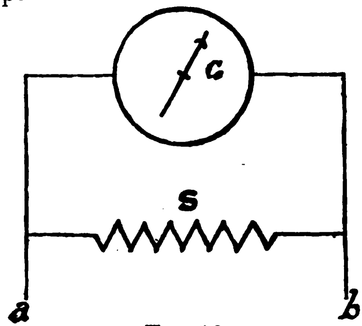
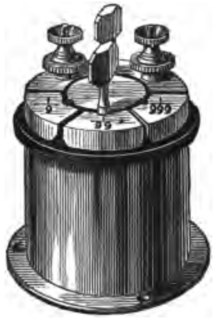


FIG. 10.

galvanometer, part of the current passing will go through S and part through the winding of G. In this capacity S constitutes what is known as a shunt to the galvanometer G, and, by the proper apportioning of the value of S in terms of the ohm or unit of resistance, having due regard to the like fixed resistance of G, we can so control matters that we know exactly what fraction of the total current passing from *a* to *b* is going through G, and from this fact we can in consequence calculate the total current passing. It will readily be seen from this that by making S adjustable within the required limits, the current actually passing round the coils of the galvanometer G can be reduced to a practical working limit, thus increasing the direct range of the instrument.

The shunts usually employed are three in number, viz., 1-9th, 1-99th, and 1-999th part of the total resistance of the galvanometer which is in circuit at the time. These three shunts respectively reduce the currents flowing through the instruments when they are severally inserted, to the 1-10th, 1-100th, and 1-1,000th parts of the total current flowing in the circuit, and they are usually marked and known as the 1-10th, 1-100th, and 1-1,000th shuffle. They are wound non-inductively, and are usually made up in box form, as illustrated in the accompanying sketch, the respective extremities of the coils being brought up to suitable metal blocks on the insulating lid, and provided

with openings for a plug, by the manipulation of which they can be placed in circuit or withdrawn as desired.



Ordinary Pattern Shunt Box, by Elliott Bros.

Without entering into theory, the writer would call the attention of readers to the fact that the formula for calculating the true galvanometer reading is as follows:—

Actual reading on scale multiplied by

$$\frac{\text{Resistance of Galvanometer} + \text{res. of Shunt.}}{\text{Resistance of Shunt.}}$$

The latter fraction, generally simplified to the initial letters thus:— $\frac{G + S}{S}$ is technically known as the *multiplying power of the shunt*, and is a useful formula to bear in mind.

From the foregoing context it will be obvious that galvanometers having different resistances require special shunt boxes, wound to such values as are indicated by the fractions 1-9th, 1-99th, and 1-999th, previously alluded to, or, in other words, every galvanometer requires its own set of shunts. To overcome this obvious disadvantage, another system of shunts has been introduced of late years, and is being generally adopted with up-to-date instruments. It is known as the "Universal Shunt System," in that the same set of shunts can be applied universally to each and every galvanometer within certain practical limits; its principle is represented diagrammatically in Fig. 11, where G represents the galvanometer as before, and S the shunt resistance, which is, however, in this case, permanently

connected across the galvanometer terminals. *a* and *b* are, as before, the wires leading in from the current source, of which *a* is directly connected to the

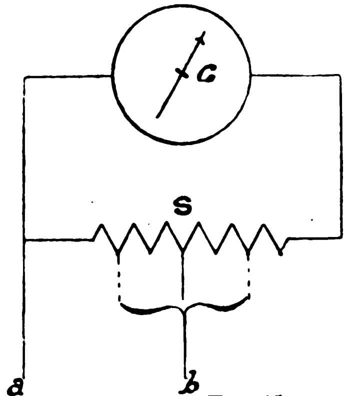


FIG. 11.

galvanometer and one extremity of S, whilst *b* is by suitable means made adjustable with regard to its point of contact with S. By a proper apportioning of the contact positions on S, which detail, as it involves certain theoretical explanations, we will not enter upon here, the same result is obtained as in the ordinary shunt system, viz., the passage of 1-10th, 1-100th, or 1-1,000th part, as the case may be, of the total current, through the galvanometer G, whilst the attendant advantages of adaptability to instruments of varying resistance are too apparent to need further comment here.

The above system has been successfully applied to a special switch combination for insulation testing, which will be described later.

The Wheatstone Bridge.—We now come to a consideration of another very important item in an electrical testing installation, viz., the Wheatstone Bridge, or set of proportional resistances, which is a necessary adjunct to the great majority of electrical tests.

In order to describe the Wheatstone bridge proper, it is necessary in the first instance for the reader to gain an insight into the principles underlying its utilisation for testing purposes, and to this end we will refer to Fig. 12,

which will be a familiar diagram to the majority of readers. A, B, C, D is a parallelogram, representing the ultimate disposition of four distinct resistances to the passage of an

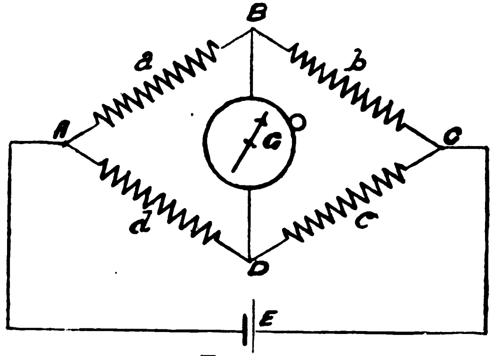


Fig. 12.

electric current. Across the points B and D is connected a galvanometer G, and across A and C the testing battery E. We will represent the resistances A B, B C, C D, and D A by the letters *a*, *b*, *c*, and *d* respectively, then, when no current flows through the galvanometer G under the conditions depicted above, *i.e.*, when B and D are at the same potential $a:d::b:c$, a simple proportion, into the theoretical explanation of which we will not enter here; suffice it to say that it is so, and that the combination forms a very useful arrangement for the measurement of resistances, *a* and *d* being commonly known as the "proportional arms," *b* as the "adjustable arm" of the bridge respectively, and *c* being usually filled by the unknown resistance which it is required to measure.

The Wheatstone bridge, as commonly constructed for practical use, consists of a series of coils of platinoid wire wound non-inductively, *i.e*, the wire is doubled back upon itself and wound double upon the insulating bobbin; by this means any inductive effects due to a current flowing through one half of the winding will be counteracted by the same current when flowing back along the contiguous path provided for it. The extremities of the coils which are accurately wound to the required resistance by comparison with certain standards, are brought up to massive brass

blocks screwed to the upper surface of a slab of ebonite which forms the lid of the containing box. The blocks are shaped as in Fig. 13, which is a side view of the ebonite lid, and some of the coils as they appear when removed from the case. The object of the chamfering on the underside

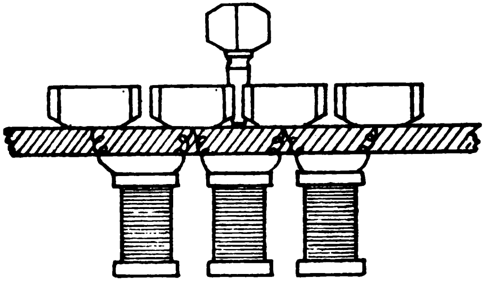


FIG. 13.

of the blocks is to allow clearance for the removal of dust and dirt, which will collect even under the most favourable conditions on the surface of the ebonite, and tend, by its presence at this point, to provide a path of low resistance for the current, thereby leading to errors in the ultimate measurements taken by means of the bridge. The plugs, of which a sample is depicted above, consist of a tapered brass shank screwed and pinned into an ebonite crown of the shape exhibited in the figure, which serves as a handle for its manipulation. They fit into recesses between two contiguous blocks bored to receive them, and are accurately ground into place to ensure a perfect fit, so that no extra resistance may be introduced by loose contacts between plug and block. The office performed by a plug when inserted between two neighbouring blocks is to short circuit the resistance coil connected to them and thereby cut it out of circuit by a path of negligible resistance. A diagrammatic plan of the complete bridge, with the values usually given to the various coils is represented in Fig. 14, whilst the complete article is depicted in general view by the subsequent illustration.

The letters *a b* and *d* in Fig. 14 also represent the arms corresponding with those similarly lettered in the original Fig. 12, whilst the small circles represent the terminals usually provided on the bridge.

The spaces marked INF. are not bridged by a coil, and, in consequence, when the plugs are removed from these positions, an infinite resistance is introduced into the cir-

Fig. 14.

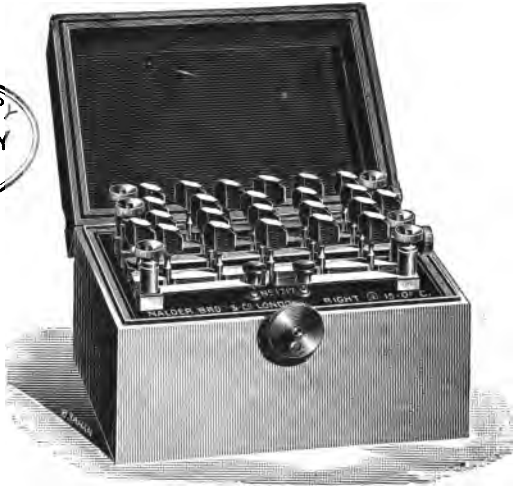
cuit, or, in other words, its continuity is totally severed, a condition of things necessary to certain tests, as will be shown later.

Large-Size Wheatstone Bridge, by Nalder Bros.

The accompanying illustration depicts what is known as the Post Office pattern of Wheatstone bridge, the only difference between it and the foregoing being that it is slightly smaller, and therefore more compact and portable, and also that two contact keys are added, one in the battery and the other in the galvanometer circuit.

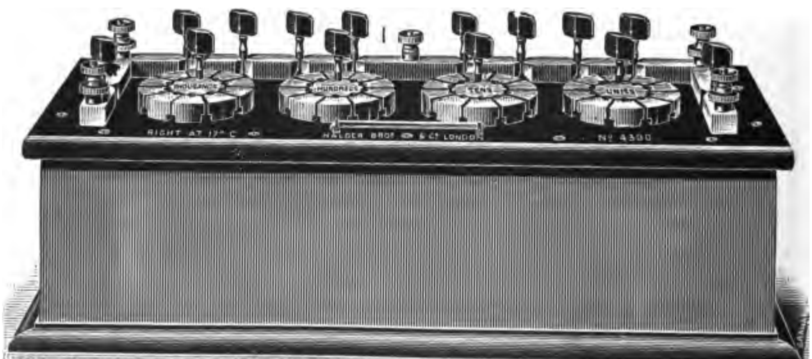
Some of the latter-day bridges are made up in "Dial" form, as shown in the accompanying illustration, the proportional arms being in a straight line, as usual, but the

adjustable arm is divided up between four circular sets of blocks, representing units, tens, hundreds, and thousands respectively, contiguous blocks round the circumference



Post-office Pattern Wheatstone Bridge, by Nalder Bros.

being connected to the extremities of the coils in numerical order, and the plugs connecting them severally to the centre piece, which, in turn, is connected to the outer extremity of the first coil in the next set, and so on.



"Dial" Pattern Bridge, by Nalder.

The advantages of this form of bridge over the preceding pattern lie in the smaller number of plugs (one to each dial), and consequent reduction of the number of movements necessary in manipulating the bridge, together with the reduced risk of bad contacts owing to loose plugs. It also possesses attendant disadvantages, in that it is not so readily cleaned, and is, in consequence, more likely to harbour dirt than the original pattern; despite this fact, it has been widely adopted, and it is questionable whether this disadvantage is not outweighed by the advantages enumerated above.

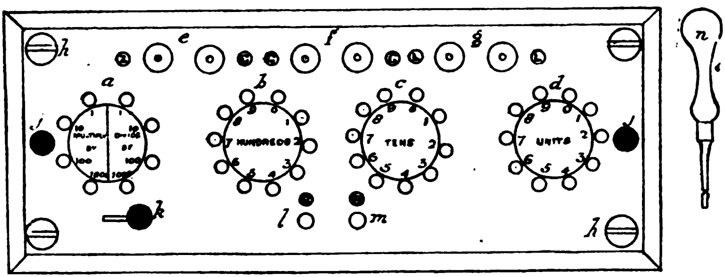


FIG. 15.

Plan of Dr. Fleming's Improved Form of Wheatstone Bridge.

(Arranged in "Dial" form.)

a Proportional arms.
b, *c*, and *d* Adjustable arm.
e Battery terminals.
f Galvanometer terminals.
g Line, or (x) terminals.
h Catches for fastening lid of bridge.
j Ebonite knobs for lifting out lid.
k Ebonite handle to automatic spring revolving dust plates.
l Galvanometer key.
m Battery key.
n Plug.

A very useful form of bridge for workshop use has latterly been put on the market by the Telegraph Manufacturing Company, of Helsby. It was designed by Dr. J. A.

Fleming, and is depicted in plan by Fig. 15. It has several novel points; the coils are of manganin wire wound non-inductively on a composite "former," consisting of two semi-cylinders of copper, separated by a centre strip of ebonite. The semi-cylinders are connected to the blocks, which are arranged in "dial" form, by lugs, and no metal work, with the exception of six convenient terminals, is exposed on the exterior of the instrument. The plugs resemble brad-awls, being provided with hard wooden handles, as illustrated; they are normally placed in a rack fixed to the side of the containing box, and pass through holes in the wooden lid before reaching the metallic blocks. When the bridge is out of use it is rendered dust proof by a system of revolving spring discs of insulating fibre, which close the apertures, and thus prevent the entrance of dust and dirt. The shanks of the plugs are grooved at a point just below the upper surface of the blocks when they are in position; this grooving effectually prevents "shouldering," a fault to which the old form of plugs were especially liable when they became worn to any extent. The proportional arms are also arranged in dial form, and a tablet with the inscriptions "multiply by" and "divide by," as applying to the resistance in circuit therein is affixed to the centre, and constitutes a great saving in memory, besides being conducive to speedy working. Two keys, in the form of press buttons, for galvanometer and battery circuits respectively, complete a very useful form of bridge.

The Wheatstone principle is also applied to yet another type of instrument, which will be found very useful in subsequent tests, to wit, the slide wire, or metre bridge.

It consists, Fig. 16, of a stout wire A B, exactly one

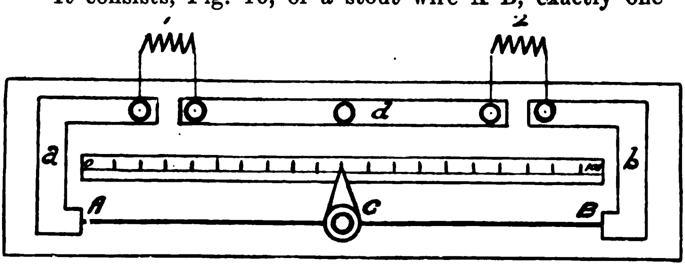


Fig. 16.

metre in length, composed of platino-iridium, or any other metal with a similarly low temperature co-efficient, stretched taut between two stout supporting straps, *a* and *b*, of copper, to which it is soldered or brazed.

d is a third copper strap mounted on the base of the instrument. Terminals are provided, as shown; C is a contact slider with a knife-edge contact piece mounted on a spring plunger, which normally maintains it out of contact with the wire A B, but allows it to make contact with the latter at one point only when depressed. It is provided with an index finger exactly in a line with the point of contact, which indicates on a metre scale suitably divided and placed behind the slide wire as shown. 1 and 2 are a standard coil of adjustable resistance, and the unknown quantity to be measured respectively. The mode of using the instrument will be readily understood; the galvanometer is connected between C and *d*, and the battery to *a* and *b*; the slider C is then moved until, when the contact plunger is depressed, no current flows through the galvanometer. The same proportion then holds as before, viz., 1 : A C : : 2 : C B. The wire A B having been carefully standardised in respect of homogeneity of resistance throughout its entire length, this quantity will be directly proportional to the respective lengths A C, C B, as indicated on the attached scale, the readings on which in degrees can therefore be utilised in working out the above proportion.

Standards.—Electrical measurements, pure and simple, consist, like other measurements, in a comparison of the object to be measured or tested with certain known standards, which comparison determines what fraction or multiple of a certain predetermined unit or standard the said object contains, in much the same manner as that in which, when weighing a certain object, we determine how many pounds, ounces, grains, etc., would produce a position of equilibrium in the balance-beam or other weighing apparatus employed for the purpose given certain standard pounds, ounces, grains, etc., in the opposite scale pan.

The electrical quantities with which we are chiefly concerned in the pages to follow are:—

(1) Electromotive Force, or Difference of Potential.
(2) Current. (3) Resistance. (4) Capacity.

Electromotive Force, commonly denoted by the letters E.M.F. corresponds, to employ a simple analogy, to the pressure or quantity tending to produce motion, as in the case of water, for example, we speak of water in a pipe as exerting a pressure of so many pounds to the square inch; in a similar manner the E.M.F. of an electric current is that pressure or force tending to produce motion, which causes the current to traverse certain paths.

The practical unit or standard of electromotive force is the *volt*. There is no battery or constant source of current which yields exactly one volt of E.M.F. between its terminals, the usual standard employed in this connection is therefore Clark's Standard Cell, the E.M.F. of which is approximately 1.454 B.A. volts at 15 degs. C.

The Clark's cell possesses electrodes of pure zinc, and similarly pure mercury, exposed to the voltaic action of a saturated solution of mercurous sulphate and zinc sulphate in water. As a matter of fact, the above-named salts are made up in the form of a paste, beneath which is placed the mercury, whilst the zinc element is embedded in it.

The Board of Trade rules for preparing the cell are as follows:—

"SPECIFICATION B.

"On the Preparation of the Clark Cell.

"*Definition of the Cell.*

"The cell consists of zinc, or an amalgam of zinc with mercury, and of mercury in a neutral saturated solution of zinc sulphate and mercurous sulphate in water, prepared with mercurous sulphate in excess.

"*Preparation of the Materials.*

"1. *The Mercury.*—To secure purity it should first be treated with acid in the usual manner, and subsequently distilled *in vacuo*.

"2. *The Zinc.*—Take a portion of a rod of pure redistilled zinc, solder to one end a piece of copper wire, clean the whole with glass-paper or a steel burnisher, carefully removing any loose pieces of the zinc. Just before making up the cell dip the zinc into dilute sulphuric acid, wash with distilled water, and dry with a clean cloth or filter paper.

"3. *The Mercurous Sulphate.*—Take mercurous sulphate, purchased as pure, mix it with a small quantity of pure mercury, and wash the whole thoroughly with cold

distilled water by agitation in a bottle; drain off the water, and repeat the process at least twice. After the last washing, drain off as much of the water as possible.

"4. *The Zinc Sulphate Solution.*—Prepare a *neutral* saturated solution of pure ('re-crystallised') zinc sulphate by mixing in a flask distilled water with nearly twice its weight of crystals of pure zinc sulphate, and adding zinc oxide in proportion of about 2 per cent. by weight of the zinc sulphate crystals to neutralise any free acid. The crystals should be dissolved with the aid of gentle heat, but the temperature to which the solution is raised should not exceed 30 degs. C. Mercurous sulphate treated as described in (3) should be added in the proportion of about 12 per cent. by weight of the zinc sulphate crystals to neutralise any free zinc oxide remaining, and the solution filtered, while still warm, into a stock bottle. Crystals should form as it cools.

"5. *The Mercurous Sulphate and Zinc Sulphate Paste.*—Mix the washed murcurous sulphate with the zinc sulphate solution, adding sufficient crystals of zinc sulphate from the stock bottle to ensure saturation, and a small quantity of pure mercury. Shake these up well together to form a paste of the consistency of cream. Heat the paste, but not above a temperature of 30 degs. C. Keep the paste for an hour at this temperature, agitating it from time to time, then allow it to cool; continue to shake it occasionally while it is cooling. Crystals of zinc sulphate should then be distinctly visible, and should be distributed throughout the mass; if this is not the case, add more crystals from the stock bottle, and repeat the whole process.

"This method ensures the formation of a saturated solution of zinc and mercurous sulphates in water.

"*To set up the Cell.*

"The cell may conveniently be set up in a small test-tube of about 2 centimetres diameter, and 4 or 5 centimetres deep. Place the mercury in the bottom of this tube, filling it to a depth of, say, .5 centimetre. Cut a cork about .5 centimetre thick to fit the tube; at one side of the cork bore a hole through which the zinc rod can pass tightly; at the other side bore another hole for the glass tube which covers the platinum wire; at the edge of the cork cut a nick through which the air can pass

when the cork is pushed into the tube. Wash the cork thoroughly with warm water, and leave it to soak in water for some hours before use. Pass the zinc rod about 1 centimetre through the cork.

"Contact is made with the mercury by means of a platinum wire about No. 22 gauge. This is protected from contact with the other materials of the cell by being sealed into a glass tube. The ends of the wire project from the ends of the tube; one end forms the terminal; the other end and a portion of the glass tube dip into the mercury.

"Clean the glass tube and platinum wire carefully, then heat the exposed end of the platinum red hot, and insert it in the mercury in the test tube, taking care that the whole of the exposed platinum is covered.

"Shake up the paste and introduce it without contact with the upper parts of the walls of the test tube, filling the tube above the mercury to a depth of rather more than one centimetre.

"Then insert the cork and zinc rod, passing the glass tube through the hole prepared for it. Push the cork gently down until its lower surface is nearly in contact with the liquid. The air will thus be nearly all expelled, and the cell should be left in this condition for at least 24 hours before sealing, which should be done as follows:—

"Melt some marine glue until it is fluid enough to pour by its own weight, and pour it into the test tube above the cork, using sufficient to cover completely the zinc and soldering. The glass tube containing the platinum wire should project some way above the top of the marine glue.

"The cell may be sealed in a more permanent manner by coating the marine glue, when it is set, with a solution of sodium silicate, and leaving it to harden.

"The cell thus set up may be mounted in any desirable manner. It is convenient to arrange the mounting so that the cell may be immersed in a water bath up to the level of, say, the upper surface of the cork. Its temperature can then be determined more accurately than is possible when the cell is in air.

"In using the cell, sudden variations of temperature should, as far as possible, be avoided.

"The form of the vessel containing the cell may be varied. In the H form, the zinc is replaced by an amalgam of 10 parts by weight of zinc to 90 of mercury. The other materials should be prepared as already described. Contact is made with the amalgam in one leg of the cell, and with the mercury in the other, by means of platinum wires sealed through the glass."

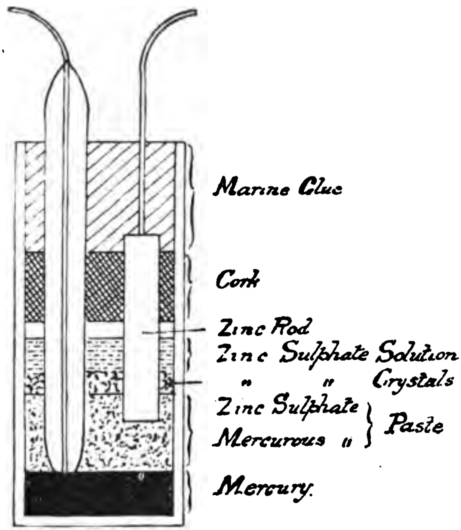


FIG. 17.

A Clark's cell, made up according to the foregoing instructions, is represented in section by Fig. 17, which is approximately full size.

The voltage of this cell is very constant at a fixed temperature, but varies with a corresponding variation in temperature, the formula for calculating its E.M.F. at a given temperature being:—

$$1\,454\ [1 - .00077\ (t^\circ - 15^\circ)\ ]\ \text{volts.}$$

Modifications of the Standard Cell.—Clark's standard cell, as specified by the Board of Trade, is almost universally adopted as a standard of electromotive force, but there are, nevertheless, several modi-

fied forms both of this and other well-known types of primary battery which possess attendant advantages and disadvantages, rendering them more or less suitable, according to the local conditions governing the case in which their employment as standards is required. It is of these modifications, and their several merits and demerits, that I propose treating in the next few paragraphs, and shall commence by dealing with the larger section, viz., the *Modifications of Clark's Standard Cell.*

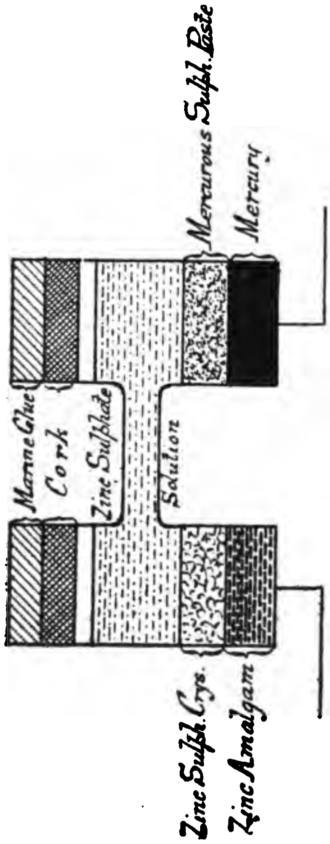


FIG. 18.

Before entering upon this discussion, however, I would draw attention to the conditions essential to any satisfactory standard cell, as enunciated by Mr. John Henderson, D.Sc., F.R.S.E., in a recent article on the subject, which appeared in the *Electrical Engineer*. They are as follows:—

"(1) The standard cell must be easily made and reproduced.

"(2) The E.M.F. of such a cell must remain constant under constant physical conditions.

"(3) The nature of the alteration of the E.M.F. of such a cell with altered physical conditions must be accurately known.

"(4) The E.M.F. must return to its original value when the original conditions are reproduced.

"(5) All impurities likely to occur in the materials of which the cell is composed should produce a negligible effect upon the E.M.F."

The Rayleigh H-Type of Clark Cell is somewhat different to the Board of Trade standard mainly in its constructional form, which, as the name implies, is in the form of the letter H. A diagrammatic elevation of the cell is represented in Fig. 18, from which it will be seen that the electrodes, as also the solid and semi-solid portions of the electrolyte are placed in separate glass containing vessels communicating through a narrow glass connecting tube by means of the liquid portion of the electrolyte, instead of, as in the B.O.T. form, being superimposed in one containing vessel.

The pure zinc electrode of the B.O.T. form is replaced by an amalgam of zinc and mercury in the proportion of 10 per cent. by weight of zinc to 90 per cent. of mercury. This amalgam is surmounted by a layer of zinc sulphate crystals, whilst the mercury in the other containing tube is covered with the usual mercurous sulphate paste. The whole of the remaining space above the level of the connecting tube is filled with a saturated solution of zinc sulphate produced at 30 degs. C. The containing tubes are sealed by corks and marine glue, as in the B.O.T. form previously described, and connection is made with the electrodes by means of platinum wires fused through the glass bases of the containers.

Dr. A. Muirhead's Form of Clark Cell is a modifica-

tion designed with a view to portability. On referring to the original description (Fig. 17) of the B.O.T. standard, it will be seen that, should the cell be at any time inadvertently upset or otherwise inverted, as in transit, for instance, the mercury which forms the lower electrode would tend to displace the other elements of the cell owing to its high specific gravity, and would therefore have no difficulty in reaching the zinc rod, thus short-circuiting the cell or destroying its constan cy by amalgamation. Dr. Muirhead eliminates this difficulty by replacing the free mercury by a flat spiral of platinum wire, amalgamated in the usual manner, either by boiling in pure mercury or by immersion therein when at a red heat. The free extremity of the platinum wire is passed through the glass wall of the containing vessel and fused therein, forming one terminal of the cell. The remaining details of this cell are practically identical with those of the B.O.T. form.

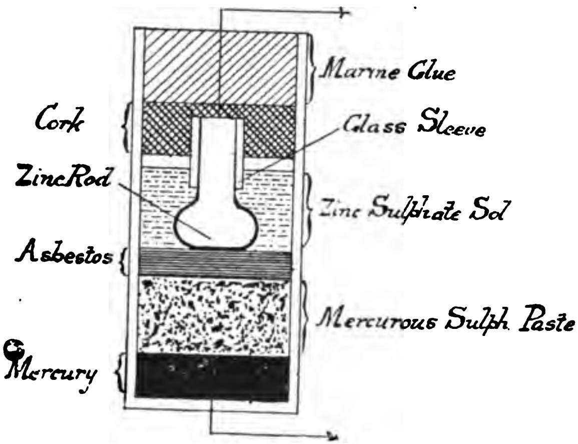


Fig. 19.

Professor Carhart's Form of Clark Cell is very similar to the B.O.T. form, but differs somewhat from it in detail. It is represented in Fig. 19. Connection is made with the mercury by means of a platinum wire fused directly through the glass. The paste is made up, as usual, and placed on the surface of the mercury. Over

this, again, is a layer of asbestos which effectually prevents contact between the zinc and mercury, whilst the former is flattened out at its lower or active extremity into the form shown in the figure, in order to increase its active surface, and is protected above from the effects of local action, which are often apparent in the ordinary form, by an encircling glass sleeve.

In its chemical synthesis this cell differs from the B.O.T. form in that the zinc sulphate solution is saturated at 0° C., instead of 30°C., and, in consequence, its resultant E.M.F. is some 0.4 per cent. higher than that of the B.O.T. form, being 1.438 standard volts @ 15° C

Professor Callendar and Barnes' "Inverted" Form of Clark Cell is specially suited for delicate work in that it is constructed with internal electrodes in a containing vessel of small diameter, thus admitting of its total immersion in a water bath for exact temperature determinations, and also from its consequently small thermal co-efficient, a rapid assumption of an even temperature on the part of the entire cell and its contents. The cell is represented in Fig. 20, from which it will be seen that the zinc electrode, as in the Rayleigh H-form of cell, is replaced by an amalgam of zinc and mercury,

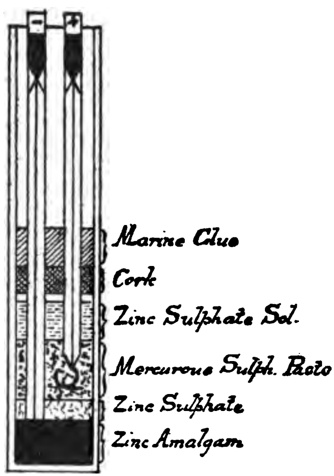


Fig. 20.

whilst the mercury appears in the form of a flattened, amalgamated platinum wire. Both these electrodes are connected by long platinum wires sealed in glass tubes with the exterior of the apparatus, the actual connection being made by means of mercury cups formed by contracting the bore of the leading-in tubes around the wires at their upper extremities. As will be seen from the figure, the actual sealing of the cell is effected some half-way down the outer containing tube, which can, in consequence, be immersed in a water bath for practically its entire length, and, owing to its small diameter, it will speedily attain the temperature of that bath.

R. Wachsmuth and W. Jaeger have constructed a cell similar to the Rayleigh H-form, in which an amalgam of cadmium, 1 part by weight of cadmium to 6 of mercury, replaces the zinc amalgam, and is surmounted by a layer of cadmium sulphate crystals. The mercury in the other tube remains the same, being covered with the usual mercurous sulphate, but the liquid electrolyte with which the cell is filled consists of a saturated solution of cadmium sulphate. The E.M.F. of this cell at a temperature of 20 degs. C. is 1.019 volt, whilst its temperature co-efficient is very much lower than that of the Latimer Clark cell pure and simple.

The above described inverted cell of Messrs. Callendar and Barnes can also be constructed with cadmium in the place of the zinc, forming portion of the electrode and electrolyte.

The well-known Daniell cell has also been adopted as a standard. A cell of this type for laboratory use is to be met with in *Dr. Fleming's Standard Cell,* which is illustrated in Fig. 21, and consists of a U-tube A B, mounted vertically on a wooden stand. The two limbs A and B of the U-tube are open at their upper extremities for the reception of stoppers carrying the electrodes Zn. and Cu., which consist respectively of chemically pure zinc amalgamated with mercury, and electro-deposited copper. When the cell is out of use the electrodes are removed from the main limbs of the tube and placed in the subsidiary tubes *a b,* which serve as containing racks until the cell is again required for use, when they are replaced in their former position. Just below the upper extremities of the limbs A B, two

branch tubes emerge, the passages of which are controlled by suitable cocks; these branch tubes are surmounted by spherical glass reservoirs C D, the office of

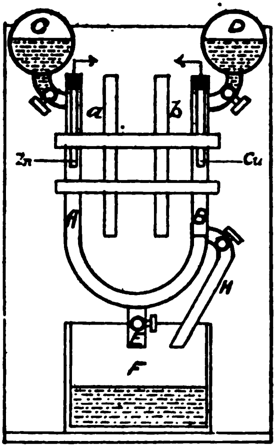


FIG. 21.

which will be alluded to shortly. A branch drainage tube E, with control clock, is taken from the bend of the U-tube, and communicates with an independent vessel F below, whilst a second similarly controlled branch H is taken from the right hand limb at the point shown, and also communicates with the same vessel F. This latter branch determines the dividing line between the two liquids forming the electrolyte, which are respectively sulphate of zinc and sulphate of copper solutions, in the limbs A and B. The reservoirs C and D contain a further supply of the corresponding solutions, which is drawn upon to replace any which may be drained off at either of the branches E or H.

As the reader will be already aware, it is necessary, when dealing with Daniell cells of the "gravity" type, of which this cell constitutes an example, to preserve a well-defined line of demarcation between the two dissimilar liquids which compose the electrolyte in order to prevent either liquid from reaching the opposite elec-

trode and thus setting up a chemical action foreign to that of the cell proper.

In the cell under notice, this line of demarcation is produced, as already stated, at the exit of the branch H, and can always be reproduced or restored to the requisite definition, if destroyed, by opening the cock at H and drawing off a portion of the combined liquids at that point, the levels in their respective limbs A B being maintained constant by a further supply from the reservoirs C D.

The operation of filling the tubes in the first instance must be systematically carried into effect. To ensure success, the experimenter must proceed as follows:—The cock controlling the reservoir C is opened, and the whole U-tube filled with the denser zinc sulphate solution; the zinc electrode, with its concomitant air-tight stopper, is next inserted in position in the upper extremity of limb A. The cock controlling branch H is then opened, and, in consequence, the level of the solution in B falls, whilst that in A remains constant; simultaneously the cock of reservoir D is opened, thus allowing the copper sulphate solution to flow gently down limb B and replace the zinc sulphate solution flowing out at H. When the line of demarcation between the two liquids reaches the level of H, all cocks are closed, and the copper electrode and its stopper inserted in position.

To ensure accuracy the copper electrode should be lightly coated by electro-deposition with a film of new copper, immediately before use.

There are two strengths of solutions usually employed in this cell. One consists in making both the zinc and copper sulphate solutions to an equal specific gravity of 1.2 at 15 deg. C., the other consists of a zinc sulphate solution of specific gravity 1.4 produced by dissolving 55.5 parts by weight of zinc sulphate in 44.5 parts by weight of distilled water, and a copper sulphate solution of specific gravity 1.1, produced by dissolving 16.5 parts by weight of copper sulphate in 83.5 parts by weight of distilled water, both operations being performed at 15 deg. C.

The resultant E.M.F. varies with the solutions employed, and is 1.102 volts with the former, and 1.072 volts with the latter.

The temperature variation in E.M.F. of this cell is .00015 volt (−) per 1 deg. C. (+).

The drawbacks to this type of cell as a standard lie in its unsuitability for transport unless empty, which fact renders it more or less a laboratory instrument, and also in the fact that minute variations in both the electrodes and the electrolyte are productive of appreciable errors in the resultant electromotive force of the cell.

Grotian's Form of Standard Daniell Cell deserves mention in that it is ingenious, easily constructed, and will stand casual short circuiting without appreciable

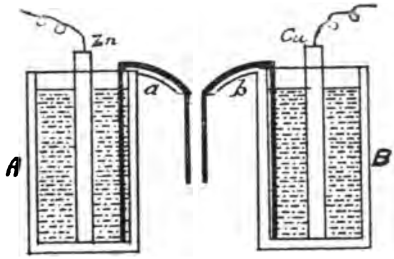


Fig. 22.

disturbance of its constancy, three qualifications which, in themselves, constitute the value of this form of cell as a standard.

Its principle will be understood on reference to Fig. 22, in which A and B are two separate containing vessels, in which are placed vertically the electrodes Zn and Cu, consisting respectively of pure amalgamated zinc and electrolytic copper. They are held in place by suitable grooves or supports in the containing vessels, and are immersed in their respective solutions of zinc sulphate sp. gr. 1.2, and copper sulphate sp. gr. 1.1. *a b* are projecting lips moulded on the edges of the containing vessels, and over the surfaces of which are spread the strips of filter paper indicated by the thickened lines in the figure. These strips are immersed in the two liquids to their full depth, and their free extremities project beyond the two lips as shown, below the level of the liquids in the vessels A and B. Acting by capil-

lary attraction, the strips of filter paper convey the two liquids over to their free extremities, which become saturated, and the action of the cell is started by pressing the two free extremities together with the fingers until they adhere of their own accord. A gradual syphoning of the respective solutions goes on, the excess of moisture finding its escape in the form of drops, thus constantly exposing fresh surfaces of the solutions to one another. The E.M.F. of this cell is 1.101 volt, rising gradually by .001 to .002 volt per 18 hours when standing idle. Its internal resistance runs into some thousands of ohms, but, as before stated, it will stand short-circuiting without appreciable alteration of the subsequent E.M.F.

There is no tangible standard of current, the practical unit being the *ampère*, but in this connection we must recall Ohm's familiar law, which has it that the current in any circuit is equivalent to the E.M.F. in that circuit divided by its resistance, the quantities named being in terms of their respective units the ampère, volt, and ohm, or, as it is commonly expressed, $C = \frac{E}{R}$

The ampère or unit of current is that current which flows through a resistance of one ohm, under the influence of an E.M.F. of one volt. In cases where exceedingly small currents have to be dealt with, as, for instance, in telephone work, a much smaller quantity is called into requisition, viz., the *milliampère*, which is equivalent to one-thousandth part of an ampère.

The unit of electrical resistance is the *ohm;* it is the resistance offered to an unvarying electric current by a column of mercury of a constant cross-sectional area of one square millimetre, and of a length of 106.3 centimetres at the temperature of melting ice.

In practice we have also the *microhm*, or one-millionth part of an ohm, and also more frequently the *megohm*, which is equivalent to 1,000,000 ohms. This latter quantity is chiefly used when expressing the resistance of dielectrics, or, in other words, the "insulation resistance" of an object.

The ohm and megohm are usually denoted by the Greek letters (ω) and (Ω) respectively; thus 2 ω means two

ohms, and 2 Ω indicates two megohms, or two million ohms. As these symbols will be adopted where necessary in the following context, it will be advisable for the reader to impress them upon his memory.

The standard ohm for practical purposes is usually made up in the form illustrated below. It consists of an accurately calibrated coil ending in the two stout ter-

Standard One-Ohm Resistance Coil, by Elliott Bros.

minals depicted in the illustration. These take the form of brass or copper rods, the outer extremities of which are brought into connection with concomitant apparatus by means of mercury cups. The coil is embedded in paraffin wax, and the brass-containing case may be immersed in a water bath up to a certain height, in order to bring it to an even temperature, which is recorded by means of a suitable thermometer also immersed in the bath, and the necessary temperature corrections applied to the subsequent results.

In Professor Chrystal's type of standard, a thermoelectric couple is added to the apparatus, one junction of which is inside, and the other outside the containing case. The couple is connected by a convenient pair of terminals to a low resistance galvanometer; if the passage of a current be indicated, the temperature of the box and the surrounding air are not synonymous, and the necessary precautions for variable temperatures must be taken; if, however, no current be indicated by the galvanometer, the exterior and interior temperatures are the same, a fact which simplifies the *modus operandi.*

Dr. Fleming has devised an improved form of standard resistance coil which is shown in the accompanying illus-

tration. The resistance itself consists of a length of platinum silver wire, treble silk-covered and ozokerited, enclosed in a circular square-sectioned trough, procured by bolting two channel-shaped rings together, a hermetical joint being ensured by the use of rubber packing. Connection to the coil is obtained by the usual stout brass or copper rods, which pass down, and are insulated from the brass tubes shown in the illustration. These tubes

Standard One-Ohm Resistance Coil, designed by Dr. Fleming, and manufactured by Elliott Bros.

are insulated at the base, where they enter the ring, by an ebonite collar, and at the apex by funnels of the same material, with corrugations in their outer surfaces. Extra insulation is attained, if necessary, by pouring insulating oil into the funnels.

The advantages of this type lie in the possibility of total immersion of the ring in a water bath, together with the extra radiation of heat afforded by the extensive area of the ring itself.

The actual unit of electrostatic capacity is the *farad*, a quantity which, however, is seldom, if ever, employed in practice, owing to the enormity of its dimensions. It is that capacity which, when charged by an ampère of current enduring for one second of time, possesses an E.M.F. of one volt.

The practical unit adopted is the *microfarad*, which is equivalent to one-millionth part of a farad, and even this quantity is usually split up into three parts, one of

which serves for the actual standard, which is thus usually given a value of one-third microfarad.

The capacity standard or "condenser," as it is technically termed, is commonly made up in the form illustrated. It consists of sheets of tinfoil sandwiched between sheets of shellac-varnished mica of a slightly larger area than the foil. Alternate sheets of the foil are connected together comb fashion, and to the two massive terminal blocks seen on the ebonite lid of the apparatus. These blocks are drilled to receive the plug shown, which should always be inserted when the condenser is out of use in order to dissipate any residual charge which might otherwise remain in it, thus leading to subsequent errors.

The ohm and volt, the respective units of electromotive force and resistance, have several different values, according to their origin. The history of the latter in detail would fill several pages with matter which is not of immediate interest here, and the writer has therefore appended the following table of comparisons by means of which the value of any particular unit can be deduced in terms of any other of the same kind.

The B.A., or "British Association" ohm, and the "Ordinary" ohm are synonymous, as are also the "Standard" ohm, the "International" ohm, and the B.O.T., or "Board of Trade" ohm:—

International	Ohm	equa's	1·00235	Legal	Ohm
"	"	"	1·01358	B.A.	"
Legal	"	"	0·99765	International	"
"	"	"	1·01120	B.A.	"
B.A.	"	"	0·98660	International	"
"	"	"	0·98892	Legal	"
"	"	"	0·9864	True	"
"	"	"	1·048	Siemens	Unit
True	"	"	1·0138	B.A.	Ohm
Siemens	Unit	"	0·9540	B.A.	"
International	Volt	"	1·00235	Legal	Volt
"	"	"	1·01358	B.A.	"
Legal	"	"	0·99765	International	"
"	"	"	1·01120	B.A.	"
B.A.	"	"	0·98660	International	"
"	"	"	0·98892	Legal	"

The reader will no doubt regard this multiplicity of values as somewhat confusing, and so, without doubt, it is, but, owing to the modifications which have been

effected from time to time by certain authoritative bodies in our system of units, this confusion is unavoidable, some instruments and apparatus having been constructed before, and some after, each modification, so that the above table of comparisons, although somewhat crude, will prove an extremely useful one to the experimenter who has to deal with a multiplicity of apparatus dating back over a long series of years.

Standard 1-3rd Microfarad Condenser, Nalder Bros.

Before departing from the subject of practical units and standards, there is one other elementary unit which one seldom sees mentioned nowadays, and that is the *mho* or unit of electrical conductivity. It is an obvious fact that the conductivity or property of permitting the passage of an electric current, of any circuit, will depend upon the electrical resistance of that circuit; as a matter of fact, it is the reciprocal of the resistance. The mho or unit of conductivity is the conductivity of a circuit having a resistance of one ohm, hence the word *mho*, suggested by Lord Kelvin, which, as will be noticed, is ohm spelt backwards.

Batteries.—For the majority of electrical tests it is obvious that we require a constant source of current; this requirement is usually filled by a primary battery numbering as many cells of such capacity as will yield the maximum E.M.F. and current required. The type of cell most commonly employed in this country for testing purposes is the ordinary Leclanché element, which in its completed form is illustrated herewith. It is universally adopted for this purpose on account of its cheapness and constancy, within certain limits; it is also the least troublesome type of cell to maintain in working

order, as, if properly set up in the first instance, it will work for months without requiring attention.

Ordinary Form Leclanché Element, by the India-Rubber, Gutta-Percha, and Telegraph Works Co., Ltd., Silvertown.

It consists of a square glass containing jar, with a circular neck; inside this is placed a porous pot containing a mixture of common gas coke reduced to granules, and powdered dioxide of manganese, in the centre of which is embedded a carbon plate. The latter has two holes drilled through it at its upper extremity, and is then immersed in molten paraffin wax for a depth of about an inch. A lead cap of the form shown in the illustration is then cast on, carrying a terminal screw and nut.

The object of dipping the upper extremity of the carbon plate in wax is to prevent "creeping" of the sal-ammoniac solution used as an electrolyte, which would otherwise tend to corrode the lead cap at its contact surfaces, and so sever the electrical continuity between cap and plate. The upper edge of the glass jar and porous pot respectively should be similarly treated with the same ulterior object, as the creeping trouble, especially in a slightly elevated temperature, will otherwise be a considerable drawback to the success of the cells.

The top of the porous pot above the afore-mentioned mixture, which is packed to within about ½ in. of its upper lip, is run in solid with marine glue, with the exception of two small vent holes, usually lined by small pieces of glass tubing, which serve for the ingress and egress of air and gas to the mixture in the porous chamber. In the outer glass jar is placed a rod of zinc, to the apex of which is soldered a length of copper wire for connecting purposes; the zinc rod requires to be well amalgamated or coated with a film of mercury before using, as otherwise what is known as "local action" is set up amongst the impurities in the zinc, and leads to the rapid destruction of the rod, which will, if properly amalgamated, last for a considerable length of time, the consumption of zinc consequent on the working of the cell being very slight.

The electrolyte, which is poured into the outer jar, consists of a saturated solution of chloride of ammonium, or sal-ammoniac, as it is more generally known. The solution is in the first instance poured into the jar to such a height as to completely fill it. The cell is then left for a few hours, when the level of the liquid will be found to have fallen an inch or more, due to its passage through the walls of the porous partition.

For light work, such as insulation resistance measurement and condenser work, where an infinitesimal current is taken from these cells, the saturated solution of sal-ammoniac will be in itself a sufficient charge, but where larger currents are taken, as, for instance, in Wheatstone bridge work, etc., an inch or so of crystals should also be placed at the bottom of the outer jar in order to maintain saturation and thus keep the cell up to its work.

If worked too rapidly, the E.M.F. of this cell falls quickly owing to consequent polarisation, but if left to itself, will recoup within a comparatively short period. Its normal voltage is approximately 1.5, though when first set up it will be found to yield as high an E.M.F. as 1.6. The number of these cells required varies greatly with the test in which they are to be utilised, and may be anything between 1 and 500. If the number be small, they may be made up in box form, separated by

suitable partitions and provided with handles for mobility; where, on the other hand, the number is large, they should be mounted on insulated trays supported in suitable stands, placed in such a position that the cells are freely accessible on all sides for repairs, renewals, and recharging.

The Leclanché element is also made up in sets of a suitable number of cells for portable purposes. In this case, however, the cells are smaller, contained in square ebonite boxes sealed with marine glue, and the porous pot combination is replaced by an agglomerate block made up of the same materials, moulded under pressure and maintained in shape by an addition of gas tar or other suitable cohesive to the mixture.

Another form of cell which is largely used for testing purposes in America and on board ship is Warren de la Rue's chloride of silver cell. Its popularity is probably due to its portability, the voltage and output of the cell being unaffected by the agitation consequent on moving from place to place. In its elementary form it is shown in Fig. 23.

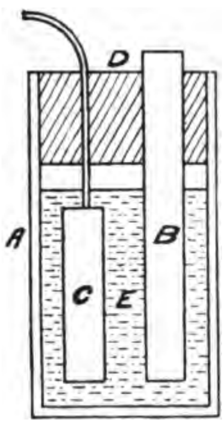


FIG. 23.

It consists of a cylindrical glass containing jar, A, closed by a block or stopper, D, of paraffin wax. B is a rod of chemically pure zinc, which constitutes the posi-

tive electrode, whilst C is a pencil of chloride of silver into the upper extremity of which is cast a silver connecting wire which leads to the exterior of the cell. This chloride of silver pencil is usually enveloped by a sleeve of parchment paper, and constitutes the negative electrode. The electrolyte, E, is a solution of 23 grammes of pure sal-ammoniac in one litre of water. This cell has an E.M.F. of 1.03 B.A. volts.

Still another form of battery which has been largely adopted for testing purposes is the Minotto modification of the Daniell cell. It consists, Fig. 24, of a glass or highly-glazed stoneware containing jar A, at the bottom of which is placed a disc of copper, B; a copper connecting wire is *rivetted* to the latter, and, insulated with

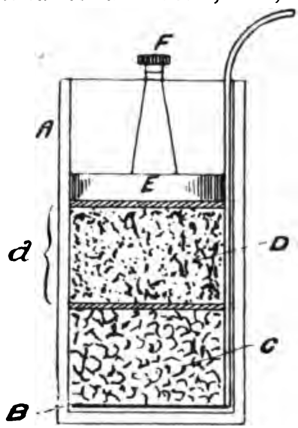


Fig. 24.

gutta-percha, is led up at the side to the exterior of the cell. On the copper disc is placed a layer of copper sulphate crystals, C, then a disc of thin cancas, *d*, surmounted by a layer of sand or sawdust, D, the former for stationary cells, the latter for the portable type. On this again is placed another disc of thin canvas, *d*, and finally the thick zinc electrode, E, on which is cast a brass terminal cap, F.

The electrolyte consists of a solution of zinc sulphate in water, which is poured in so as to cover the zinc plate,

E. It is better, when primarily setting up the cell, to moisten the sand or sawdust in the first instance with the electrolyte, squeezing it almost dry again before placing in the cell, as this proceeding facilitates the permeation of the liquid, and consequent rapid working up of the cell. Its E.M.F. is approximately that of the Daniell cell proper, viz., 1·079 B.A. volts.

Secondary batteries or accumulators have also been applied to testing purposes, and, from their comparatively constant discharge rate, would impress one as being eminently suitable, but they require constant attention and perfect insulation, the former being a matter which involves time and labour, and the latter a condition not easily obtainable in any enclosure containing secondary cells, owing to the acid fumes, etc., emitted thereby, so that they have not been altogether a success. Of course, there are some cases where, in dealing with extremely low resistances, a comparatively heavy current of short duration is needed for a small period; where this is so, accumulators are a necessity, but a stand-by of from one to five cells will generally be found ample for anything of the kind.

Thus far the writer has only dealt with three distinct types of primary battery for testing purposes; there are, of course, a hundred and one other types, all capable of yielding a current more or less constant; but this does not profess to be a work on the ubiquitous primary cell, and the types enumerated above are those more generally adopted for testing purposes, and will therefore serve the purpose of the writer by comprising the battery section of instruments and apparatus.

Keys, Switches, &c.—Of keys, switches, and contact devices there are many types. It will serve our purpose fully if we deal with the principal ones here, viz., those which will be essential to the subsequent tests to be described in these pages.

The Simple Circuit Key.—This useful piece of apparatus comprises a device for closing or completing any circuit at will, and is usually constructed as shown in Fig. 25, where A consists of a flat brass spring, mounted at one extremity on an ebonite block or insulating pillar B, and free at the opposite extremity as regards its ver-

tical movements within certain limits, which enable it to "make" and "break" contact at will with the stud C, which is platinum tipped, as well as the corresponding point on the spring, in order to reduce the electrical resistance due to oxidation at the point of contact. D is a finger piece used to depress the spring, and it is generally provided with a locking device E, engaging with

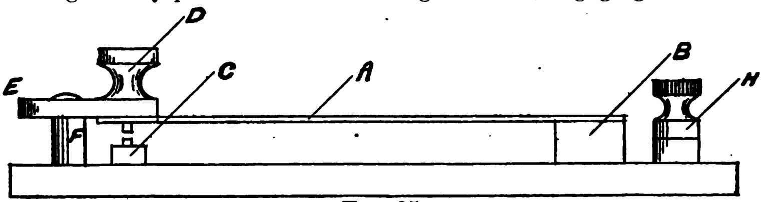


FIG. 25.

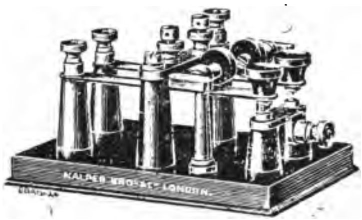
the stud F, which enables the operator to leave the key closed for any required period. H is one of the terminals, the remaining one being in a line with it, and therefore not seen in the figure. They are, of course, connected with the spring A and the stud C respectively.

The Short-Circuit Key.—This is an extremely useful key, and is essential to the safe working of all sensitive galvanometers. It is connected across the terminals of the instrument, and its office is to form an alternative path of negligible resistance for the current, or, in other words, to short-circuit it and thus put it out of action.

Galvanometer Short Circuit Key with Locking Piece, by the India-Rubber, Gutta-Percha, and Telegraph Works Co., Ltd.

It is an exceedingly simple key, consisting of a straight brass spring, mounted on an insulated base and provided with a terminal. Normally, this spring rests in contact with the platinum-tipped extremity of a screw mounted in a bridge piece, which is also connected to the remaining terminal. At its free extremity the spring is provided with an ebonite finger-piece, by means of which it can be depressed out of contact with the second terminal on to an insulating ebonite stud. To keys of this type illustrated above a revolving ebonite catch, engaging with a fixed stud on the base, is added, in order that the key may be kept depressed automatically for any desired length of time without the attention of the operator.

The Reversing Key.—This useful piece of apparatus, illustrated below, is employed, usually in the battery circuit, for connecting either pole of the latter to the circuit at will, or,



Ordinary Pattern Pillar Reversing Key on Ebonite Base by Nalder Brothers.

when necessary, for totally disconnecting it. The key is represented in diagram by Fig. 26, A and B being the two brass contact springs, which are mounted on insulating ebonite pillars fixed in an ebonite base piece, as shown in the completed illustration above. The springs pass under, and normally make contact with, platinum-tipped screws in the bridge-piece C, whilst at their free extremities they are provided with platinum contact studs, arranged opposite to similar studs on the bridge-piece D below. All these several parts are, like the springs A and B, mounted on insulating pillars, so that the key is highly insulated, a necessary precaution in most tests. Four terminals are provided, as shown by the small circles, the battery being connected to the two marked (+) and (−) and the remainder of the circuit to the other pair.

The action of the key will be easily understood; if one of the springs, A, for example, be depressed, it is brought into connection with the (–) negative pole of the battery, whilst the remaining spring, B, is in contact with the (+) positive pole and *vice versa*. The direction in which the battery current is flowing through the circuit may thus be reversed at will, or checked altogether by simultaneously releasing both springs.

This key is a facsimile of the double "tapper" key used in single-needle telegraphy. In some types the contact

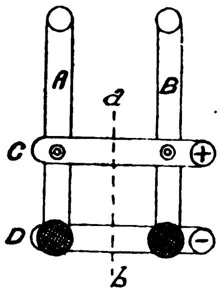


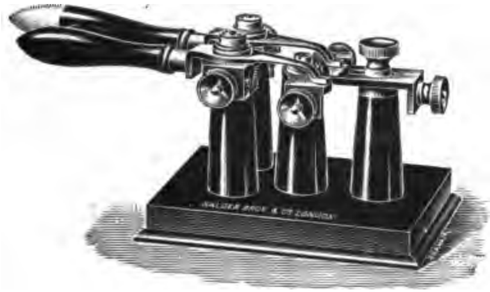
Fig. 26.

bars C and D are divided at the centre, as indicated by the interrupted line *a b*, and provided with terminals at either end; when this is the case, the two halves can be disconnected when desired, and employed as separate keys.

Like the preceding one, this form of key is also provided with a device for automatically holding the springs down when depressed. It consists of an ebonite cam, engaging with the top of the spring, and mounted on a horizontal spindle, which is actuated by a suitable handle, and revolves in a trunnion, which, like all other parts of the key, is mounted on an insulating pillar; one of these cams is fitted to either spring.

In some cases, the foregoing key takes the form of the reversing switch shown below, which was designed by Mr. J. Rymer Jones. In principle and resultant action, it is precisely similar to the reversing key described above, and possesses the attendant advantage that all contacts made through it are of a sliding or rubbing nature, thereby eliminating all danger from bad contacts, etc., which

might, and occasionally do, accrue from using keys in which all contacts are procured by pressure pure and simple.



Rymer-Jones Reversing Switch, by Nalder Brothers.

Condenser Keys.—A familiar key much used in condenser work is here illustrated both diagrammatically and *in toto*. It consists (Fig. 27) of two brass springs, A and B, connected by a bridge-piece C, which carries a terminal as shown, and also serves as a support for the springs,

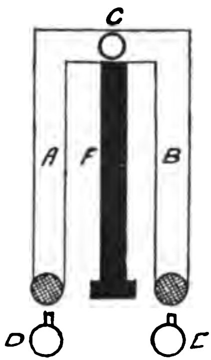
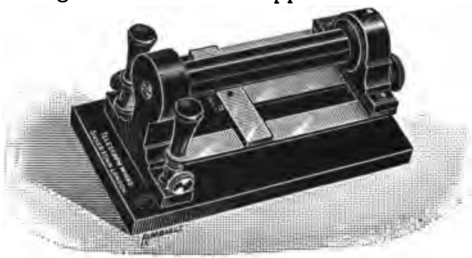


Fig. 27.

being mounted on a horizontal ebonite arm F, carried by a short ebonite pedestal mounted in the base. The springs A and B are provided with the usual platinum-tipped contact studs on the under side of their free extremities, which

make contact when depressed by the finger-pieces with two similar fixed contact studs, D and E, which are connected to the remaining terminals of the apparatus.



Lambert's Condenser Discharge Key by the India-Rubber, Gutta-Percha, and Telegraph Works Company, Limited.

The mode of using this key is as follows:—The terminal C, and, consequently, both of the springs A and B, are connected to one side of the condenser, one of the remaining terminals is connected to the battery circuit, and the other to the galvanometer. Depressing the spring on the battery side of the key for a definite period charges the condenser and the key is then released, thus leaving the latter insulated; the opposite spring is then depressed, and the condenser immediately discharges itself through the galvanometer circuit.

Webb's Discharge Key.—A key which performs a similar office to the above is illustrated below, and is known as Webb's condenser discharge key.

A (Fig. 28) is a solid brass lever of rectangular section, pivotted at *a*, and normally maintained in contact with the upper pin, B, by means of the spring *b*; when depressed by

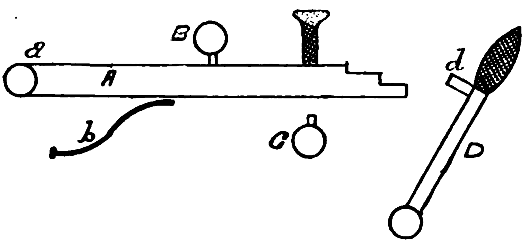


Fig. 28.

means of the finger piece, it breaks contact with B, and makes with C below. D is a pivoted ebonite arm carrying a detent, *d*, engaging with the end of the lever A, which is "stepped" as shown. The three terminals are indicated, as before, by circles, and the *modus operandi* is extremely simple. A is connected to the condenser, B to the galvanometer, and C to the battery. Depressing A, the condenser is brought into connection with the battery for charging. The lever is automatically held in this position by engaging the detent *d*, with the top step; at the end of a predetermined charging period, the lever D is drawn out slightly, allowing A to release itself, under the influence of the spring *b*, as far as the second step; in this position A, and consequently the condenser, is insulated. On totally withdrawing the lever D, with its accompanying detent, A is released, and makes contact with B, thus discharging the condenser through the galvanometer circuit.

Plug Switches.—The ordinary battery connections of a testing set are usually brought direct to a plug switch from which they are again led off to the instruments. These plug switches are of multifarious design, from the simple reversing switch, shown in Fig. 29, to a regular distributing board, consisting of a series of massive brass blocks, each connected to a desirable point in the battery, such as 1, 5, 10, etc., cells, and brought into connection as desired with

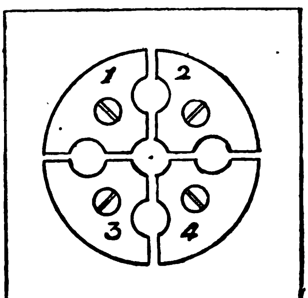


FIG. 29.

a common 'bus bar by means of the accompanying plug. The switch shown in Fig. 29 consists of four brass segments, 1, 2, 3, and 4, mounted on

an insulating ebonite base piece. The battery leads are brought to two opposite ones, such as 1 and 4, and the leading wires from the remainder of the apparatus to the other two, 2 and 3. The simultaneous insertion of two plugs on one or other of the two diameters of the circle connects the battery with the instruments in one or other direction, as may be desired.

The foregoing descriptive series of instruments and apparatus will serve to complete this section. There are one or two combinations of apparatus with which the reader will be acquainted at a later stage, as it is necessary in the first instance for him to master the elementary principles of simple testing in order that he may the more readily grasp the advantages and uses of such combinations.

We will pass on, therefore, to the practical application of the foregoing details to actual testing.

Practical Testing.

(1) *Continuity, or Circuit, Test.*—The simplest test of all, and one which forms the actual basis of the majority of subsequent tests to be dealt with in this series, is the simple continuity, or circuit test, the object of which is to ascertain the existence or non-existence of a complete circuit through which it is possible or impossible, as the case may be, for an electric current to flow.

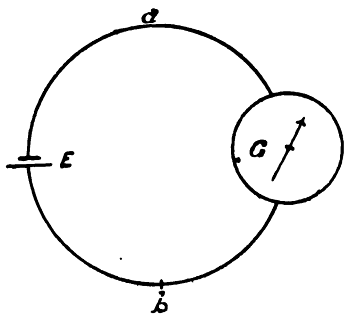


Fig. 30.

Referring to Fig. 30, which represents a simple circuit containing a battery E, and a galvanometer G, we note

that the current from the battery will, if the circuit be complete, as shown in the figure, flow through the galvanometer by way of *a* and *b*, and a deflection of the galvanometer needle will result. If, however, we destroy the continuity of the circuit by severing one of the connecting wires, as, for example, at the point *b*, the current will cease to flow, and the galvanometer will remain passive. This is the principle of continuity testing. The instruments and apparatus required for the test are a battery and galvanometer of the type known as "detector," the construction of which was indicated in Fig. 2; as regards the battery, the number of cells required depends upon the nature and resistance of the circuits to be tested, but, for ordinary electric light, telegraph, and telephone work, where the circuit resistance does not exceed two or three hundred ohms, a couple of cells will be ample for the purpose.

The method of procedure is exceedingly simple. The battery E and galvanometer G are connected up as shown in Fig. 31, *a* and *b* being flexible leads of a suitable length for the work in hand. These leads are applied simultaneously to the two extremities of the circuit under test; if a deflection be obtained on the galvanometer then the circuit is complete; if, on the other hand, no deflection be obtained, there is a solution of continuity, and the fault must be localised.

To localise a disconnection the best plan is to divide the circuit up into suitable sections; thus, if it be an ordinary branch of electric light house wiring, from the switchboard to a lamp or lamps, the wiring from switch to ceiling-rose may be regarded as one section, ceiling-rose to lamp-holder as another, and so on; in this way it is an easy matter to find out in what part of the circuit under test the disconnection exists, and to remedy it accordingly.

In many cases what is known as an intermittent disconnection will occur, whose presence may be detected in the following manner. The leads *a* and *b* are connected to the two extremities of the section under test, and the galvanometer carefully watched; if, as before, there be no deflection at all at the end of a few minutes, then, the disconnection may generally be regarded as total, but if intermittent oscillations or flickings of the needle be obtained, it signifies a disconnection in which the severed parts are periodically making contact with one another; cases of

this description often occur in which a wire has become broken and the two severed ends are held together by the surrounding insulation which remains undamaged. Other cases of intermittent disconnection frequently occur with overhead telephone wires which break, and, remaining suspended over adjacent wires, are brought into intermittent contact by the agency of the wind.

The National Telephone Company adopt the above simple system of circuit testing universally for daily line tests and fault localisation, each exchange being provided with a detector outfit and special switching arrangements, by means of which it can instantly be connected with any required line at will.

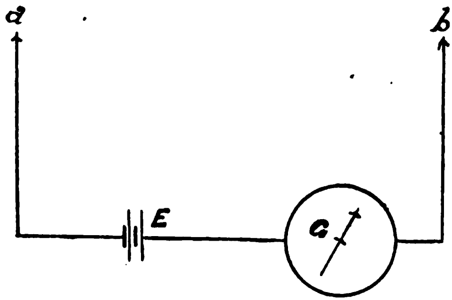


FIG. 31.

A very good method of determining an intermittent disconnection on a dynamo, or any local electrical apparatus which may be accessible to the operator, is as follows:—The section in which the fault lies having been localised as before described, the leads *a* and *b* are connected to its extremities, and, the galvanometer being carefully observed, a sharp blow is struck the object under test, with a wooden mallet or other object calculated not to injure the surface in any way. The vibration thus set up in the mass of winding will frequently separate two broken ends if they be in contact, or bring them together if they be apart, a resultant flick being observed as before on the part of the galvanometer needle, thus effectually determining the existence of a fault.

The methods of continuity or circuit testing described above are, of course, very rough, and give no indication as

to the ohmic resistance of the circuit under test; a fault may thus exist which is of high resistance but sufficiently small to indicate a complete circuit when subjected to the detector test. In such case there is nothing for it but to measure the resistance of the circuit by the methods to be described later; the excessive value then obtained will be a sufficient indication of the existence of a fault.

The familiar law of Ohm is almost too well known to need repetition here, but, as it concerns the principles of all electrical testing, it is herewith submitted to the reader once again. The current flowing in any circuit is equivalent to the electromotive force in that circuit divided by the total resistance thereof, or, as it is more commonly expressed, $C = \frac{E}{R}$, the quantities involved being in terms of their respective practical units, to wit, the ampère, volt, and ohm.

Thus, if we refer to Fig. 30, which represents a simple circuit, Ohm's law tells us that the current in ampères flowing from, say, the positive pole of the battery E, through *a*, the galvanometer G, *b*, and the battery itself, back to that positive pole, is equal to the E.M.F. in the circuit which, as in this case there is no other source of current, will be the E.M.F. of the battery E (in volts), divided by the total resistance of the circuit (in ohms), which latter will include the resistance of the galvanometer G, and connecting leads *a* and *b*, together with the internal resistance of the battery E.

It is obvious, therefore, that in order to analyse the condition of this circuit when a current is flowing through it, we must first arrive at the respective resistances of the galvanometer G and battery E, and we will now proceed to discuss one or two methods of:

(2) *Galvanometer Resistance Measurement.*—There are two very good methods of taking the resistance of a galvanometer, known respectively as the "Half Deflection" and "Equal Deflection" methods. The galvanometer whose resistance is to be measured, is connected as shown in Fig. 32, where G is the galvanometer, E the testing battery of one or more cells, according to the sensitiveness of the instrument under test, and R an adjustable resistance, such, for instance, as the adjustable arm of a Wheatstone bridge. If the galvanometer be of a sensitive type, it will be as

well to introduce a short-circuit key across its terminals, and, if considered necessary, an ordinary circuit key, or switch may be included in the circuit, but these accessories

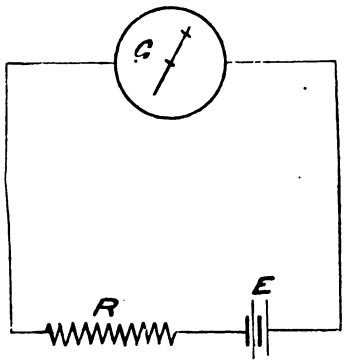


Fig. 32.

have been omitted in the figure for the sake of clearness. The half deflection method consists in making R a certain fraction of what the galvanometer resistance is likely to be, and noting the deflection obtained on the galvanometer G when the circuit is completed. Now, increase the value of R to R1 such that the deflection obtained through it is equal to half the original deflection, then the resistance of the galvanometer will be equal to the increased resistance R1 less twice the original resistance R, or, expressed as a formula, $G = R1 - 2R$.

The connections for the equal deflection method are precisely those represented in Fig. 32 for the foregoing test with the one addition of a shunt, s, across the terminals of the galvanometer. The battery in this case must be of low resistance. Note the galvanometer deflection as before, with the shunt, s, connected; then disconnect s and increase R to R1, such that the same deflection is obtained as before, then resistance of galvanometer $(G) = s\,\dfrac{R1-R}{R}$

A still more reliable method of taking the resistance of a galvanometer is that known as the Wheatstone bridge method of resistance measurement, which has already been

alluded to, and will be described later in detail. It involves the use of a second galvanometer in taking the test. If the galvanometer under test be of the reflecting type previously described in these pages, its suspended system should either be temporarily removed or suitably supported, in order to protect it from any injury which might accrue from the passage of the testing current. The temperature in the immediate vicinity should also be taken at the time of making the test, as the resistance varies with a variation in temperature; in the case of copper it increases about 0.21 per cent. per 1 deg. F. rise in temperature, or about 0.38 per cent. per 1 deg. C. This quantity is known as the *temperature co-efficient*, and it varies with different metals, its value for copper being comparatively high. For this reason, copper is seldom used nowadays in the winding construction of electrical instruments and apparatus, but is replaced by such alloys as manganin and platinoid, the temperature co-efficients of which are so low as to be almost negligible.

(3) *Battery Resistance Measurement.*—Here, again, we have a still greater multiplicity of available methods. It is obvious, of course, that we cannot measure the internal resistance of a current-producing cell as we can the resistance of a coil, for example, because the current from the cell itself would oppose or aid the current from the testing battery, as the case may be, and thereby introduce considerable error into the result. In the case of a large number of cells, all of equal resistance and E.M.F., such as a battery of accumulators, for instance, the resistance can be taken by the Wheatstone method, by splitting the battery up into two halves and opposing them to one another, thus taking the combined resistance which will, of course, be equal to that of the whole battery in series; if necessary, one or two extra cells may be allowed in one half to supply the testing current.

When the above mode of procedure is not possible, it is necessary to adopt one of the following methods:—

What is known as the reduced deflection method consists in connecting up as in Fig. 32; in this case the galvanometer should be of low resistance, such that its resistance added to that of R will be a fraction of the resistance of the battery E. Note the initial deflection as before, we will call it *d*, then increase the value of R to R1

and note the lesser deflection d_1, then the resistance of the battery

$$= \frac{R_1\, d_1 - Rd}{d - d_1} - G$$

Matters will be considerably simplified if R_1 be made of such value that the second deflection, d_1, is exactly half the first, for in such a case $E = R_1 - (2R + G)$.

A still simpler modification consists in shunting the galvanometer by a short stout wire, such that the combined resistance of galvanometer and shunt is a negligible quantity. The battery and galvanometer are first connected up *per se*, and a deflection obtained and noted; the resistance R is then introduced, and regulated to such a value that the original deflection is halved, then $E = R$, from which it will be seen that the required internal resistance of the battery is read off directly from R.

Mance's method of measuring the resistance of a battery is represented diagrammatically in Fig. 33, where *a*, *b*, and *c* represent the proportional and adjustable arms respectively, of a Wheatstone bridge, G a galvanometer, E the battery under test, and K an ordinary circuit key or switch. The method consists in adjusting *c* until the manipulation of

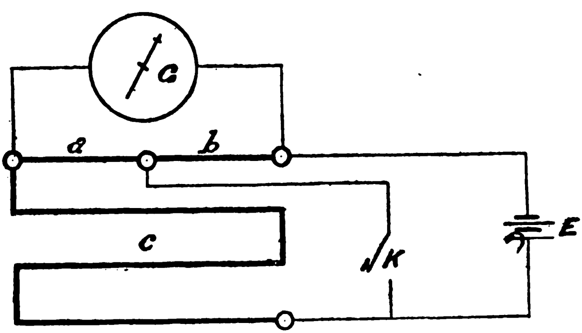


Fig. 33.

the key or switch K has no effect upon the galvanometer G, or, in other words, *c* is brought to such a value that the deflection of the galvanometer needle remains the same

whether K be open or closed. When the required result has been obtained, the resistance of the battery

$$E = c\frac{b}{a}$$

Thomson's method is indicated in Fig. 34, where E represents the battery under test as usual, G the galvanometer,

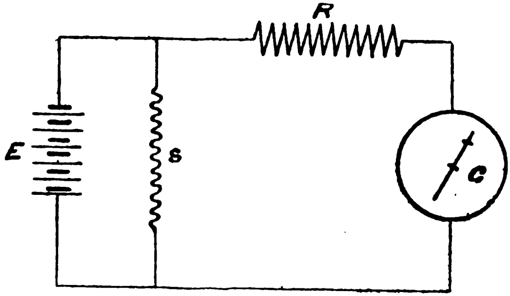


FIG. 34.

R an adjustable resistance, and *s* a shunt across the terminals of the battery. In order to carry out this test, we require, in the first instance to know the resistance in ohms of the galvanometer G and the shunt *s* respectively. The mode of procedure is as follows: The connections being made as in Fig. 34, the galvanometer deflection is noted, and the shunt *s* is then removed from the circuit, R being simultaneously increased to R1 such that the resulting deflection on the galvanometer is the same as before, then the resistance of the battery E

$$= s\,\frac{R1 - R}{R + G}$$

The internal resistance of a battery when it is supplying energy to an external circuit, differs from its internal resistance when idle, owing to the chemical reactions set up within the cells, and other causes. In many cases it is necessary to ascertain this internal resistance of the cells when at work, and Fig. 35 represents a method of effecting this. E represents the battery under test, supplying current to the external resistance R under control of the key

or switch K; *s* is a shunt across the battery terminals, the value of which in ohms should be between that of the battery itself and double its value, but neither more nor less for satisfactory working. It is inserted or cut out of

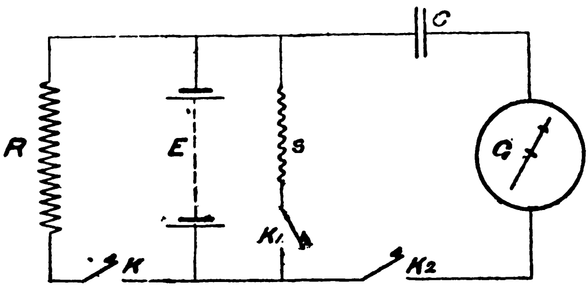


FIG. 35.

circuit at will by the key K1. C and G are a condenser and galvanometer respectively, whose presence in the circuit is controlled by K2.

The *modus operandi* is as follows: Close K, and, if the current be steady, open it again and close K2, noting the resultant deflection *d*. Now open K2 and again close K until the galvanometer reaches zero, when again open K and close K1 and K2 in rapid succession, taking care to note the second deflection *d*1, then the resistance of the battery

$$E = s\,\frac{d - d1}{d1.}$$

Of course, this method does not actually determine the battery resistance whilst working, but immediately after the cessation of work; for this reason the keys K1 and K2 should be manipulated as soon as possible after K has been opened.

If the external load be fairly constant, the same connections will answer for an actual test whilst working. To effect this, depress K permanently, or, if necessary, cut it out of circuit. Close K2 and note the resultant deflection *d*, then, with K2 still closed, close K1, which will give rise to a deflection in the reverse direction *d*1, then the battery resistance E

$$= s. \frac{dl}{d - dl - \frac{dls}{R.}}$$

The quantity $\frac{dls}{R}$ may be neglected if the value of R be high, *i.e.*, if the resistance of the external circuit be large, whilst, if the battery be idle, and R be in consequence, totally disconnected it disappears altogether and we have

$$E = s \frac{dl}{d - dl}$$

Next on our list comes an all-important test which will invariably be met with in any electrical undertaking, and to which we have already several times referred, viz.,

(4) *Resistance Measurement by the Wheatstone Bridge Method.*—The connections for this test have already been indicated in the previous pages by Fig. 12, a familiar diagram utilised in explaining the principle of the Wheatstone bridge, but it is reproduced in more practical form in Fig. 36.

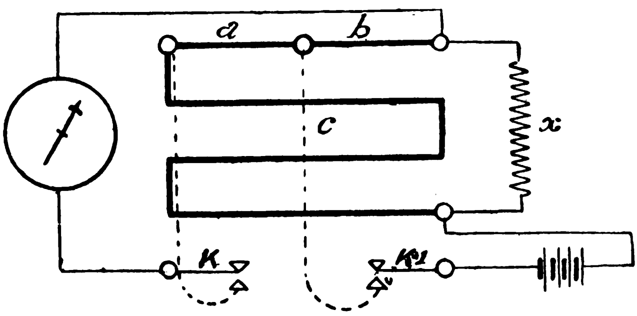


Fig. 36.

The apparatus required for this test are a moderately sensitive galvanometer, the previously described P.O. pattern of Wheatstone bridge for simplicity's sake (including keys) and some half-dozen cells of a suitable type, such as the Leclanché or Daniell. Connect up as shown in Fig. 36, x being the unknown resistance which it is required to measure. If possible, it is advisable for the operator to

gain a rough insight as to the probable resistance of x before commencing the test, as matters are thereby simplified by the preliminary manipulation of the bridge plugs. Where such approximate information is at hand, and the probable result is comparatively low in value, arrange for a large resistance in a, and a small one in b, and *vice versâ* if the probable result be high. If moderately in the centre range of the instrument, equal resistances may be plugged in the proportional arms. The INF plugs must not be withdrawn for this test. Having unplugged the requisite proportional resistances, arrange the adjustable arm, if possible, for an approximate result, remembering that the unknown resistance $x = \frac{b\ c}{a}$

Now depress the battery key K1 first, and subsequently the galvanometer key K, when, if a deflection be obtained, remove or insert plugs in c until no deflection results when K is depressed, K1 being kept down all the while.

In cases where no idea exists as to the probable result, a balance must be obtained on the galvanometer by manipulation of the plugs, the best plan being to start with the thousands, and obtain a reversal of the deflection; then work down to the hundreds, tens, and units, obtaining final adjustment over the range of the latter. If no reversal can be obtained by any arrangement of plugs, the unknown resistance x is probably beyond the range of the bridge, its resistance being very high or extremely low.

When a case occurs in which it is impossible to obtain an exact balance on the galvanometer, the addition or subtraction of one unit in the adjustable arm giving two different deflections in opposite directions with regard to the zero point, the following formula for calculating x will be found efficient:—

Let a and b be the values of the proportional arms.
Let c be the lower value of the adjustable arm.
Let $c1$ be the higher value of the adjustable arm.
Let d be the deflection resulting from c.
Let $d1$ be the deflection resulting from $c1$.

$$\text{Then } x = \frac{a}{b}\left(c + \frac{d}{d + d1}\right)$$

The same method of resistance measurement is also applicable to the metre bridge, previously described. This method, although not quite so accurate in its results as the preceding one, is nevertheless very handy, and suitable for workshop practice. Its accuracy mainly depends on the uniformity of the actual slide wire considered with regard to its ohmic resistance. The connections are represented in Fig. 37.

The apparatus required is the same as in the preceding test, with the exception of the Wheatstone bridge, which is in this case replaced by the metre bridge. As will be seen from the diagram, the standard resistance *a*, and the resistance to be measured, *x*, are inserted in gaps 1 and 2. In practice it is as well, if circumstances permit, to make *a* approximately equal to *x*, thus having the equivalent of equal values in the proportional arms of the Wheatstone bridge. This arrangement will enable the slider to be adjusted somewhere near the centre of the slide wire. It will be noticed in Fig. 37 that an extra key for the galvanometer is added to take the place of that which in the P. O. pattern of Wheatstone bridge is usually fitted on the ebonite top of the instrument itself. The battery key is provided for by the action of the slider itself, which makes and breaks contact with the slide wire at will.

The method of conducting the test is precisely similar

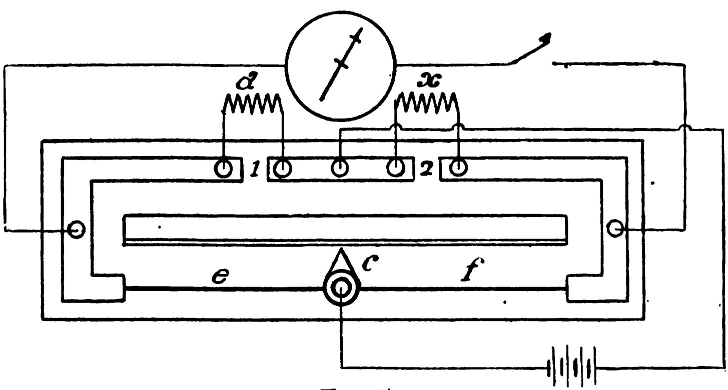


Fig. 37.

to the foregoing, the adjustment and consequent galvanometer balance being, however, effected by moving the contact slider *c* along the wire in one or the other direction, instead of, as in the previous test, manipulating plugs.

The formula for calculating the result is the same as in the case of the Wheatstone bridge proper, viz., $x = \frac{a.\ f}{e}$, the resistances *e* and *f* being represented by the number of divisions on the slide wire scale contained within them, which lengths, as the wire is homogeneous throughout, are proportional to the respective resistances of these sections.

When the resistances which we have to measure are of such magnitude that they cannot be included within the range of the average Wheatstone bridge, they develop into what are technically known as *dielectric* or *insulation resistances*, and require to be treated accordingly.

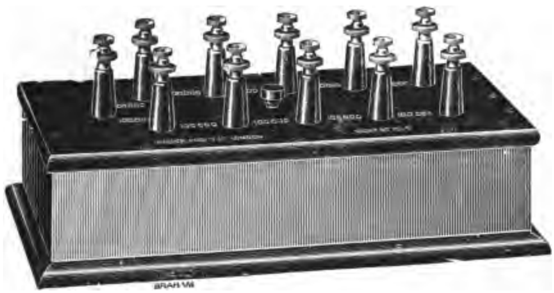
The dielectric, or, as we shall term it, insulation resistance of an object, such, for instance, as a length of wire or cable, is the electrical resistance of the media separating that object from the earth or any contiguous conductor, and it is usually calculated in megohms, the megohm, as already stated, being equivalent to one million ohms.

A totally different system of measurement is necessary in cases where such high resistances are dealt with, and the method most commonly adopted is that of comparison, a method which consists in electrically comparing the resistance to be measured with a standard resistance having a high value.

Such standard resistances are frequently as high as one megohm, and can be constructed in several ways. One type, which is illustrated below, consists of a number of bobbins wound with very fine wire to a resistance of some 100,000 ohms apiece, and connected up in series to the required total of one million ohms.

Another and cheaper form of standard is constructed by Messrs. Johnson and Phillips, of Charlton, Kent, as follows. An oblong strip of plate glass, some 8 ins. long by 4 ins. wide, A, Fig. 38, has two holes drilled through it, at the respective centres *a* and *b*, of the two ends.

On the ground surface of the glass is drawn with a very hard 6 H plumbago pencil, a zig-zag line some $\frac{1}{8}$ in. in width, connecting the two holes. This is well rubbed



Standard Resistance Box of one megohm, subdivided into sections of 100,000 ohms apiece, by Messrs. Nalder Bros. and Co.

into the surface of the glass, and expanded round the holes *a* and *b* as shown, to form a sort of lug. Terminal bolts and nuts are then passed through the holes, and, tinfoil washers being interposed between them and the glass, are screwed up very tightly, in order to bring the tinfoil into intimate electrical contact with the particles of plumbago forming the lugs. The combination thus obtained is tested for resistance in the ordinary way,

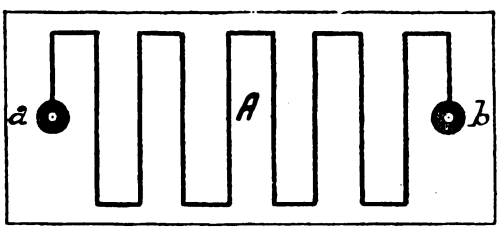


Fig. 38.

and, if too high, is subjected to more pencilling until the value is brought approximately to the required dimensions. The whole of the surface carrying the plumbago is then carefully varnished with a thin shellac

varnish, and baked in front of a gas flame until fairly hard. Several subsequent coats of varnish are applied and treated in like manner; the plate is then allowed to cool to its normal temperature, and the final test taken to ascertain its finished value. It is then mounted in an ornamental wood base with an ebonite top and insulated terminals, and the final value as a resistance is stamped upon the ebonite in the usual manner. There is, of course, a certain amount of luck attending the manufacture of these standards, which determines the ultimate value obtained, but these are usually sufficiently approximate for all practical purposes, and, if the pencilling and subsequent baking have been carefully carried out, these standards will retain their value for many years without attention, although, of course, they require careful handling.

Having so far described the additional apparatus required, we will proceed with—

(5) *Insulation Resistance Measurement.*

The connections for this test are indicated in Fig. 39, where G represents a high resistance Thomson astatic galvanometer of the type already described, with the adjustable 1-9th, 1-99th, and 1-999th shunt *s* across its terminals (the shunt *s* may conveniently be arranged on the "Universal" principle). K is a short-circuit key, and K1 a reversing key, which, however, in practice is normally replaced by the Rymer Jones reversing switch, but the key is represented here for the sake of clearness. E is a battery which should be of sufficient power to yield an E.M.F. at least double that to which the object under test will be subjected under normal conditions of everyday work. R is the standard megohm or other high resistance, whilst C is the object under test, which is in this case a length of cable.

The method of conducting the test is as follows:—The instruments are first connected as shown in the figure, the oable C being omitted as indicated by the dotted connection. One side of K1 is depressed, thus connecting one pole of the battery through the galvanometer G and the standard resistance R to earth, and the remaining pole direct to earth. Whilst keeping K1 depressed by means of its cam, the short-circuit key K of the galvanometer is gently opened, and the shunt *s*

manipulated in conjunction with it, in order to obtain the highest readable deflection upon the scale, which deflection we will call *d*.

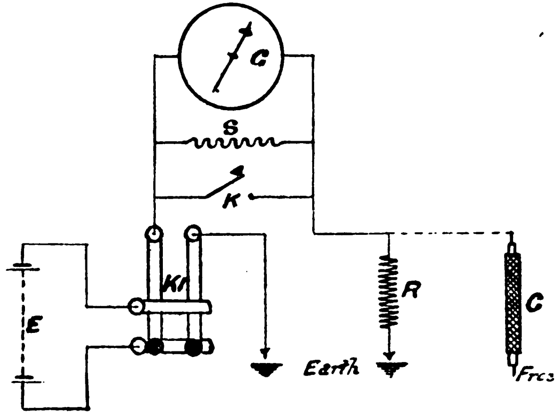


Fig. 39.

Having carefully noted *d* and its attendant shunt, the key K is closed again, and K1 released. The standard resistance R is then disconnected, and replaced by one end of the cable under test, the opposite extremity being left free. The key K1 is now again depressed, and the time noted. K is then carefully manipulated as before, until a readable deflection *dl* is obtained, which, in the case of cables, should be noted at the end of a minute from the time of depressing K1 in order to allow a suitable interval for what is known as "electrification," a term which will be described presently. In most cases, where a careful test is desired, successive readings of *d*1 are obtained at intervals of half a minute for the space of some four or five minutes, or even longer. During this period, the deflection should steadily decrease, quickly at first, and then more slowly, until its fall becomes almost imperceptible.

This property of electrification is one which the cable possesses of, as it were, absorbing a small portion of the testing current into itself, but the exact action which takes place is not thoroughly understood. This absorption is very rapid when the current is first applied, but

becomes slower as the cable approaches saturation. It also varies considerably with the temperature and material composing the insulating medium, being more marked at high than low temperatures. In the case of gutta-percha insulation, the electrification amounts to from 2 to 5 per cent. of the total deflection between the first and second minutes following the application of the current, whilst, with india-rubber insulation, on the other hand, the electrification may reach as high a value as 50 per cent. between the first and fifth minutes.

In order to ensure a steady electrification, as also to guard against surface leakage, the ends of the cable under test require to be carefully prepared before testing. To this end, the braid and tape, with which cables and wires are usually provided as an external finish and protection, are laid back for some two or three inches at either extremity of the cable, and the rubber or gutta-percha thus exposed is cleaned and scraped so as to expose a fresh dry surface to the air; in the case of rubber-covered cables this clean surface may be further ensured by paring the rubber down after the manner of sharpening a cedar pencil, with a keen knife.

The ends thus prepared are immersed for a few seconds in hot molten paraffin wax, which has been previously purified. This treatment serves to provide the extremities of the cable with a moisture-resisting film, which prevents surface leakage, and tends to secure the true results desired in the test.

The method of working out the results from the readings obtained is as follows:—First obtain the true value of the observed deflections by multiplying them by the fraction $\frac{G + s}{s}$, which constitutes what is known as the "multiplying power" of the shunt, G and s being the respective resistances of the galvanometer and shunt in ohms. It amounts, in short, to multiplying the deflections obtained with the 1-9th shunt by 10, with the 1-99th by 100, and with the 1-999th by 1,000 respectively, for, let G equal 9,000 ohms, then if s be the 1-9th shunt, it will be equivalent to 1,000 ohms, and

$$\frac{G + s}{s} = \frac{9{,}000 + 1{,}000}{1{,}000} = \frac{10{,}000}{1{,}000} = 10.$$

Having obtained the two deflections in this manner, we next proceed to determine what is technically known as the "insulation constant," which consists in multiplying the deflection *d* obtained through the standard in the first operation by the value of the standard R in megohms and fractions of a megohm. This proceeding gives us a number, the magnitude of which will, to a certain extent, determine the accuracy to which it is possible to work in obtaining results; the higher the value of the constant the greater the ultimate accuracy. With a delicate galvanometer and a battery of some 400 Leclanché elements, it is quite possible to obtain a constant having a value of one million, but lower values will, of course, suffice for all ordinary purposes.

Having obtained our constant, all we have to do is to divide it by $d1$, the deflection obtained through the object under test.

The insulation of a cable is usually stated in megohms per mile or some other unit of length; thus, if the cable under test be two miles long, and we obtain a deflection of 200 deg., the true deflection for one mile of the cable will be 200 deg. divided by 2, or 100 deg.

The electrification may advantageously be plotted in the form of a curve, the degrees and time being registered on the vertical and horizontal ordinates respectively. In this manner any unsteadiness is at once detected by a fluctuation in the curve.

In practice, the insulation tests on a cable are usually taken with the zinc pole of the battery on the cable and the carbon or copper, as the case may be, to earth, but, if a check be needed, and more especially in the case of submarine cables, readings are taken with both poles of the battery consecutively, and should correspond with one another if due care be taken to discharge the cab'e thoroughly between the respective applications of the current.

A further check is provided by what are known as "earth readings." If we disconnect the battery from the cable at the end of, say, five minutes, and connect it (the cable) instead to earth through the galvanometer, we shall obtain a series of gradually decreasing readings which should fall practically to zero at the end of another five minutes from the time at which the bat-

tery was disconnected. These readings should be carefully noted at similar intervals to those of the electrification readings. If all is as it should be—*i.e.*, if the insulation of the cable under test be perfect in every respect, the earth reading at the end of the first minute, added to the last electrification reading, should be equal to the electrification reading observed at the end of the first minute, or $d1$.

In order to arrange for these earth readings in practice, we may introduce a well-insulated plug switch of two segments between the two spring terminals of K1 in Fig. 39; then, when K1 has been finally released at the end of the last electrification reading, the plug can be inserted, thus short-circuiting these two terminals, and connecting the cable directly to earth through the galvanometer G. Care must be taken to remove the plug, however, at the end of the discharge, as otherwise, when K1 is again depressed, the battery E will be short-circuited.

Now as regards the question of efficient earths. In testing a circuit which has been already wired, we have, of course, to depend upon the best earth we can get, which will usually be a water pipe; water pipes are preferable to gas pipes, as the red lead, etc., employed in jointing the latter tends to introduce a high resistance into the circuit. A small surface should be filed clean and bright on the periphery of the pipe, and the earth connection bound tightly round it, and, if circumstances permit, a soldered connection should be made, as unsteadiness is often caused in otherwise careful insulation tests by the bad contact at an earth connection.

In cases where cables are tested at a factory before being installed, much better circumstances exist for the procuration of a good and efficient earth. The drums containing the cable are immersed bodily in large tanks of water, connection with which is obtained by means of a metal plate or coil of bare wire also immersed. The two ends of the cable are, of course, kept clear of the water, and are prepared and waxed in the usual manner. The cables should be in the water at least 24 hours before the test is taken on them in order to allow the water to percolate thoroughly to all points, and also that the cable may have time to attain the same tem-

perature as the water, the temperature of which should be taken at the time of making the test, for dielectric resistance, like that of copper and other metallic conductors, varies with a variation in temperature.

Lead-covered and armoured cables are usually tested by making the lead covering or armour an earth, as the case may be, and, in all such cases, the earth connection should be sweated or soldered. Concentric cables and twin conductors are tested for insulation from core to core, as well as to earth. Lead-covered cables possessing a fibrous insulation, or such materials as impregnated paper, etc., as a dielectric, should all be immersed in water for testing purposes, as on the imperviousness of the lead sheathing depends the efficiency of the insulation, for, once moisture has obtained an entry by a pinhole or flaw in the lead, the hygroscopic nature of the material at once provides a direct path for it to the conductor, and a "fault" is the inevitable result.

It is a well-known fact that the more perfect the earth which surrounds the insulation of a cable or wire, the higher is the *apparent* insulation resistance of that cable. I say apparent, because the effect is due to a more rapid electrification and consequent smaller deflection at the end of one minute from the application of the current.

Thus a length of cable immersed in water which provides the earth during the test will show an apparently higher insulation resistance than the same cable when lead-covered and tested with its lead sheathing as an earth. In the same manner, a cable on which the lead sheathing is tight will yield better results than one to which it has been loosely applied. This fact is well worth specially noting, as it is liable to give rise to mistaken impressions regarding the results of certain insulation tests.

Electrification is seldom if ever experienced in testing circuits where the cable has been already installed, as the earth is in such cases very imperfect, and the deflection through the cable or wire will usually be found to settle down at once to a permanent value.

Another matter which should be noted in testing electric light and similar circuits, including a number of fittings, is this—that, although the cable or wire used

may originally have yielded under test an insulation resistance of some hundreds of megohms per mile, it will not indicate anything like this result when wired in position, owing to many reasons, chief amongst which may be mentioned imperfect earth, surface leakage at fittings, etc., etc.

As regards the temperature co-efficient for dielectrics, this varies considerably with the nature of the material, no two samples being exactly alike; it is, in consequence, impossible to lay down a hard and fast rule to suit all insulating media, but, in exceptional cases, an approximate co-efficient can generally be obtained from the manufacturers, who determine it by dint of experiment. As a matter of fact, in cable factories, the testing tanks are usually provided with the necessary steam fittings for raising the temperature of the water to any required degree, and the tests are taken at that temperature, usually 60 deg. Fahr. for india-rubber and 75 deg. Fahr. for gutta-percha.

Government specifications commonly provide a table of temperature co-efficients of dielectrics for the testing electricians of the manufacturers to work to, but it is very questionable whether such tables are ever correct for the particular sample under test. Red-tape, however, prevails, as usual, even in such details.

The "straining," "stressing," or, as our American cousins term it, "puncture" test of insulated cables and wires intended for use in high tension circuits takes the form of a practical application of an alternating current of given voltage for a definite period, rather than the galvanometer test to text-book rule, described in the preceding paragraphs, although this test should also be instituted in every case, both *before* and *after* the stressing test, as I shall proceed to explain.

All insulated cables and wires intended for use on circuits at a voltage of 500 and upwards should, after having been subjected to the usual insulation test by the direct deflection method previously alluded to, be subjected to an alternating voltage at least twice that at which they are ultimately intended to work, whilst immersed in a tank of water at zero potential, or, in other words, connected to earth, or the remaining terminal of the generator. If lead-sheathed or metal-armoured, the sheathing or ar-

mouring, of course, takes the place of the water *except* in the case of cables insulated with a dielectric of fibrous disposition, in which case, the imperviousness of the lead sheathing governs the value of the insulating medium, and should be tested whilst submerged.

The testing current is usually obtained from an alternator of suitable output, generating at, say, 200 volts, and is raised to the required value by a step-up transformer, or bank of transformers, the primaries (low tension) being connected in parallel, and the secondaries (high tension) in series. The high tension portion of the plant requires to be well insulated, and, to this end, the transformers are usually removed from their metal cases, and mounted on insulating stands, care being taken to connect the secondaries in the right direction, so that they assist rather than oppose one another. A well-insulated lead is taken from one terminal of the secondary circuit to one extremity of the cable under test, the opposite extremity of the latter being left free as in ordinary insulation testing. It is necessary to state here that the extremities of the cable require an equally careful preparation for the prevention of surface leakage in this case as in that previously described under the heading of "Insulation Resistance Measurement." The remaining terminal of the secondary circuit is connected to earth as represented by the water in the tank, or the metallic sheathing of the cable; if the latter, the connection should be soldered.

The connections as described above are represented diagrammatically in Fig. 40, in which A is the alternator, T1, T2, and T3 a series of three step-up transformers, B an ammeter in the primary circuit, C the submerged cable, V*h* and V*l* high and low tension voltmeters respectively in the secondary and primary circuits, V*h* being of the electrostatic variety. The one V*l* serves as a check upon the other V*h*, if the multiplying power of the transformers be known. S*h* and S*l* are high and low tension switches respectively; these two switches should at least be introduced. From the point of view of safety it is better to multiply than reduce the number, as, for instance, by introducing a sub-section switch, *s*1, *s*2, and *s*3, in the primary circuit of each transformer.

The method of conducting the test is as follows: All

being in readiness, and the various switches closed, the alternator A is gradually speeded up until the voltmeter V*h* indicates the required voltage of, say, 2,000 volts. This potential is then maintained constant for a definite period, usually from 20 to 30 minutes, or even longer, when the alternator is slowed down and finally stopped, the switches being left closed meanwhile. These are then

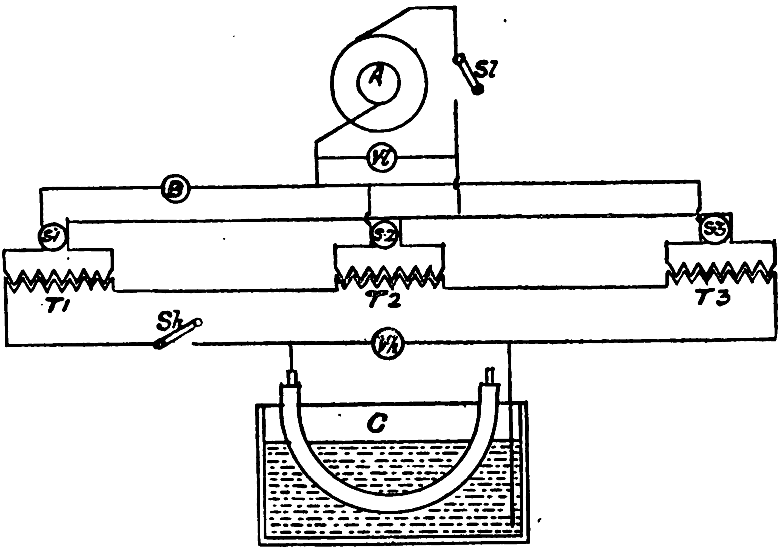


Fig. 40.

opened, and the cable put to earth for a corresponding period, in order to dissipate any residual charge which might remain in it, and interfere with the subsequent galvanometer test. The ordinary insulation test is then repeated, and the result obtained should, if the insulation be perfect, correspond exactly with that obtained before the application of the alternating potential. If it be found to have fallen in value after being duly earthed, attention should first be given to the extremities, which, in view of possible surface leakage, should be prepared afresh in the manner previously described. Should this not have

the desired effect of raising the insulation under test to its previous value, the high voltage should be again applied, when, after a more or less protracted period, the insulation will probably give way as indicated by the flicking of the ammeter needle at B, and the sudden drop in voltage as denoted by the voltmeter V*h*. The switch S*l* should be immediately opened, and the alternator shut down, when the cable can be disconnected and the fault produced by the passage of the high voltage duly localised by one of the several methods to be described later.

As regards the testing voltage applicable in each particular case, there is no hard and fast rule determining this quantity, the general procedure being to subject the cable to an alternating voltage at least twice that at which it is intended to work in practice, for a time which, as before stated, varies with different authorities, and may be anything from ten minutes to an hour, or even more. This question of voltage and time limit is one which requires standardising, and it is to be hoped that some responsible body like the British Association or the Institution of Electrical Engineers will, at no very distant date, formulate a set of rules applicable to most of the cases met with in practice, and founded on past experience on the part of leading cable manufacturers and users, who, after all, are the individuals most competent to judge in such matters.

There is no doubt now that high voltages in electric light and power distribution are becoming so prevalent in this country that the ordinary megohmic results, as obtained by the *direct deflection* and other methods of insulation resistance measurement will go for nought unless accompanied by a corresponding guarantee of resistance to alternating currents at high voltages.

It may be imagined from a brief consideration of the facts that the actual power required for the application to an insulated cable of a test of this description is very small, owing to the fact that the secondary or high tension circuit is not completed; this, however, is not the case, on account of the self-induction of the transformer circuit, the output of the testing alternator being governed by the electrostatic capacity of the cable or wire under test. In the case of considerable lengths of

fairly large cable immersed in water, the output required sometimes amounts to as much as ten or even twenty E.H.P. for a secondary voltage of from two to five thousand, and, in this connection, it is advisable to compute the power required before attempting to apply the test with what may prove to be insufficient plant for the purpose.

The aforementioned question of comparison between the direct deflection galvanometer tests before and after the stressing test, is a very important one, and should receive careful attention, inasmuch as an extremely slight drop in the insulation resistance, as recorded in terms of megohms per mile, indicates inherent weakness, and has often resulted in the ultimate breaking down of the insulation under a subsequent straining test, after an application of an hour's duration.

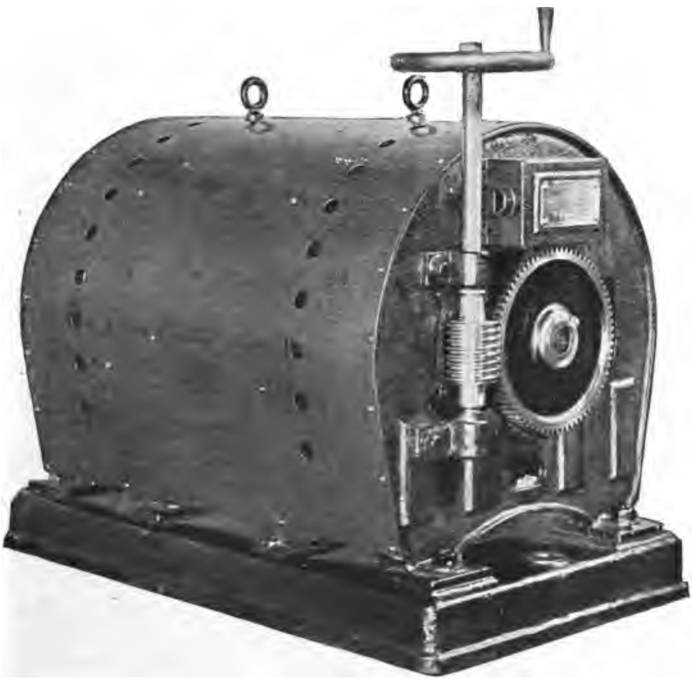
It is inadvisable to raise the testing voltage beyond a certain ill-defined limit, as it tends to strain the insulation unnecessarily, especially if, as is often the case in these days of cut prices, that insulation has been specially composed to suit a particular voltage; it is far better, under the circumstances, to repeat the original dose or voltage, and maintain it, if necessary, for a longer period, rather than run the risk of permanently straining the insulation by subjecting it to a momentary current of considerably higher tension, a practice frequently resorted to in America as a time-saving device.

In connection with the high pressure testing of insulated cables and dielectrics generally, where a high pressure alternating current is required capable of gradual adjustment over a wide range, the attendant difficulties in the way of varying the speed of the primary testing alternator may be obviated by the adoption of a special type of regulating transformer designed for the purpose, and manufactured by Messrs. Cowans, Limited, of Salford, Manchester. These useful accessories are wound for pressures of from two to three thousand volts at a normal output of 20 horse-power, and are rendered capable of supplying any required voltage between zero and these limits by a simple rotary motion imparted by a convenient handle and worm-wheel attachment. A general view of the apparatus is shown in the accompanying illustration. If higher voltages be required, this apparatus

can also be used in conjunction with a second step-up transformer, preferably of the oil-insulated type.

The main principle of the apparatus consists in a movable "shuttle" or H armature capable of rotary motion around its axis as a centre. This is encircled by a fixed, ring-shaped magnetic core; around this ring is wound part only of the secondary circuit, whilst the shuttle carries the remaining portion, together with the whole of the primary section. It will thus be seen that, by varying the relative position of the shuttle and fixed core through an angle of 180 degs., the secondary voltage can be raised from zero to maximum, or *vice versâ.*

A secondary feature in the design of this transformer consists in short-circuited or "shading" coils, which are wound on the shuttle at right angles to the active wind-



Cowan's Regulating Transformer.

ing, and serve to prevent an excessive drop of potential in the secondary winding, due to the magnetic flux set up between the two portions, fixed and movable, of the secondary circuit. By means of this latter device, the total drop in potential is reduced to 7 per cent., a very satisfactory and therefore negligible figure, especially in testing operations, where the voltage has only to be maintained for a limited period.

I am indebted to Messrs. Cowans, Limited, for the above details, which serve to explain the principle of a very useful invention.

If, as in the cases mentioned above, the cables under test be immersed in a tank, and, in fact, in many similar cases, it is more than probable that circumstances compel the placing or setting up of the testing instruments at some distance from the cable whose insulation resistance is to be determined. When this is so, a length of well-insulated lead must be run from the instruments to the extremity of the cable, and also a secondary lead, which need not necessarily be insulated, for the earth connection. Both purposes are admirably served by a length of concentric cable of small cross-sectional area, or a single insulated conductor armoured with a spiral lapping of iron or steel wire. The ends of such a lead require to be equally as carefully prepared as the actual extremities of the cable itself, and a preliminary test must be taken on the lead, its far extremity being left free, before it is connected to the cable, *d*1 and the electrification readings being noted in exactly the same manner as if the cable itself were under test. The readings thus obtained, which should, if the lead be of good quality, and of no very great length, amount to but a few degrees, are deducted from the ultimate deflections obtained through lead and cable combined, the remainders being the true reading due to the cable alone.

Departing for the time being from the subject of insulation or high resistance measurement, let us proceed to examine the methods of dealing with the opposite extreme, or

(6) *Low Resistance Measurements*, which are similarly beyond the scope of the ordinary Wheatstone bridge method of resistance measurement.

The only practicable methods of dealing with resist-

ances of very low value consist in what are known as *difference of potential* methods.

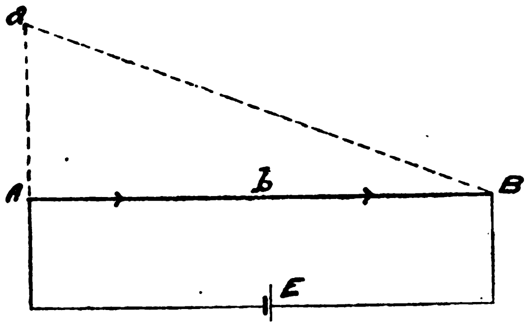


FIG. 41.

Referring for a moment to Fig. 41, it is a well-known fact that if we take a length of wire, cable, or other conductor, A B, and pass a current through it from the battery E in the direction indicated by the arrow heads, viz., from A to B, there will be an E.M.F., or, as it is often termed, difference of potential between the points A and B equal to the E.M.F. of the battery E, the resistance of the connecting wires being regarded as negligible; the potential may, in fact, be taken as falling from a maximum A *a* at A to zero at B. This fall of potential along the wire A B is directly proportional to its resistance, and it is possible for us to determine the fall, or difference of potential between any two points along the wire A B by the application of a pair of leads connected to a suitable galvanometer. We can, for example, compare the fall of potential between the points A and *b* with that between *b* and B, and, since this fall is directly proportional to the respective resistances of these sections, we can, by obtaining a value on the galvanometer for each of the two sections A *b* and *b* B, also compare their respective resistances.

The practical method of applying this principle to low resistance measurement is illustrated in Fig. 42, where A B is a standard homogeneous wire of low resistance, and B X the resistance which it is required to measure. G is a galvanometer whose connecting leads

a b can be applied at will, either to the points A B or B X. E is the testing battery of one or two cells capable of yielding a constant current (an accumulator answers

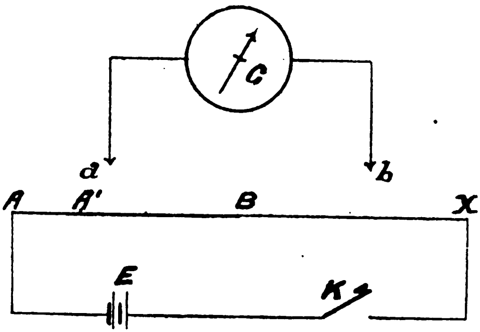


Fig. 42.

very well), and K is a simple circuit key for controlling the current supply. A B may be provided in practice by the slide wire of a metre bridge, the connection *a* being made through the slider, a proceeding which simplifies matters considerably, as will be shown presently. The method consists in applying the leads *a b* to A B and B X respectively, the key K being closed in each case. The two deflections *d* and *d*1 are duly noted, then the resistance of A B : the resistance of B X : : *d* : *d*1.

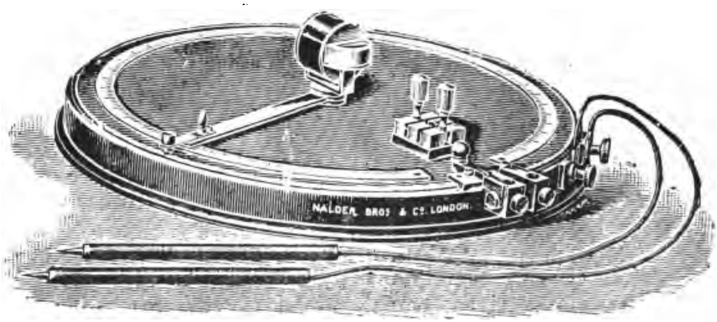
If we connect *a* to the slider, and manipulate the latter along the wire A B, until a point A′ is found, at which the deflection *d* equals *d*1, then A′ B equals B X.

It will be readily understood that in dealing with very low resistances contact will be an important matter, and so it is, in the battery circuit, *i.e.*, at any point in the circuit bounded by A B X K and E. In the galvanometer circuit it makes no difference to the test.

In order to eliminate the introduction of any extra resistance into the current circuit through bad contacts, the latter should be well made through massive terminals, or even, if need be, sweated. A better plan still is to make the contacts at A B and X through mercury cups, the ends of the wires being first well cleaned with emery paper and subsequently amalgamated by rubbing with

nitrate of mercury before their immersion in the cups. The galvanometer G for this test should be fairly delicate, in order that accurate adjustment of the slider may be obtained. One of Thomson's reflecting galvanometers, having a resistance of some four or five thousand ohms, answers very well, but should be protected by a shunt until very nearly balanced, when the final adjustment can be made with the shunt cut out of circuit. If it be available, a differential galvanometer answers admirably for this test, the two windings being connected to A B and B X respectively, *a* being adjustable as before, is manipulated until no deflection results on the galvanometer, then A′ B equals B X, as before.

Messrs. Nalder Bros. have applied this principle of low resistance measurement to an instrument which combines practically all the apparatus required upon one base. It is illustrated below, whilst Fig. 43 represents a working diagram of the apparatus.



Low Resistance Measurer by Nalder Bros., designed on the potentiometer principle. N.B.—This illustration represents the instrument in circular form, whilst the diagram, Fig. 43, is taken from the longitudinal form of apparatus.

A B, Fig. 43, is a standard homogeneous slide wire, connected by means of massive terminals in series with the resistance to be measured, X; a storage cell, E, capable of yielding a constant discharge of some 10 ampères, and an adjustable resistance, R, which is manipulated until the above current, or its approximate value, as indicated on an ammeter connected in circuit,

but not shown in the diagram, is flowing through the circuit. S is an adjustable slider, connected by means

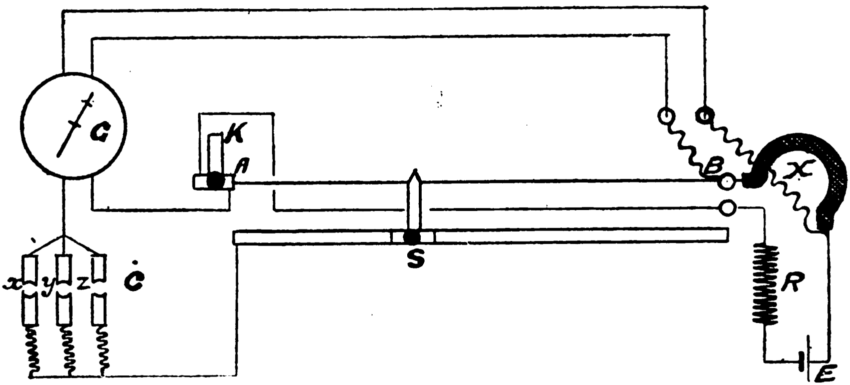


FIG. 43.

of a 'bus bar with one winding of a small horizontally pivoted differential galvanometer G, through the regulating resistances *x*, *y*, and *z*, which are controlled by the three-way plug switch C, and, by their respective insertion in the circuit, determine the subsequent values of the results obtained in 1-2,000ths, 1-1,000ths, and 1-500ths of an ohm respectively.

The slider S registers its position of contact with the slide wire on a suitably divided scale, as in the case of an ordinary metre bridge, whilst the other winding of the differential galvanometer is brought to terminals on the base, and from them, by means of flexible leads furnished at their far extremities with steel contact points, is led to the extremities of the resistance under test. These feelers, as we may term them, are represented in the figure by waved lines, and the contact between them and the ends of the resistance *x* does not affect the accuracy of the test. K is a key controlling the current circuit.

The *modus operandi* is as follows:—R, having been adjusted until the requisite current of some 10 ampères flows through the current circuit when K is closed, the plug is inserted in *x*, *y*, or *z*, as the case may be, accord-

ing to which value for the ultimate result will be nearest to the value of the resistance under test x. The slider S is then adjusted until a balance is obtained on the galvanometer G, the feelers during this operation being maintained in contact with the ends of the resistance x. The battery key K may then be released, and the scale reading carefully noted.

The scale is divided up into 100 equal parts, each of which is again sub-divided into 10 parts, and the reading indicated by the pointer when a balance is obtained will represent the resistance of x in terms of the particular fraction controlled by the plug switch C. Thus, if the plug be in y, the result may be read off the scale directly in 1-1,000ths of an ohm; if in x, in 1-2,000ths; and if in z, in 1-500ths.

Carey Foster's method of low resistance measurement again involves the use of the indispensable metre bridge. The metre bridge proper, although it has, up to the present, been represented as possessing two gaps only, 1 and 2, Fig. 37, in the thick copper strip connections, is in reality possessed of four, the two additional ones, 3 and 4, Fig. 44, being usually bridged across by thick links of copper of similar section to the main strips themselves, and offering a practically negligible resistance to

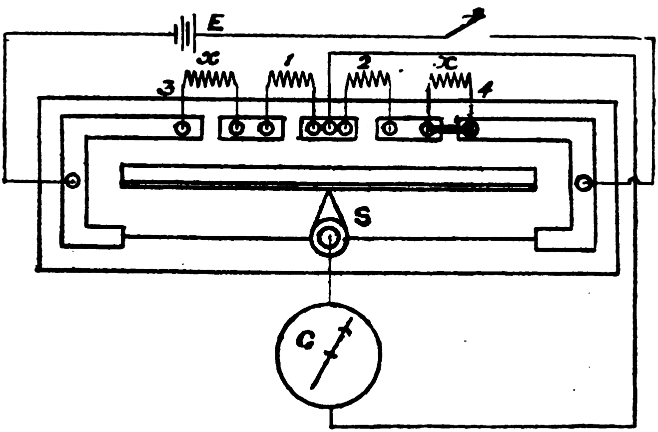


FIG. 44.

the passage of an electric current. In Carey Foster's method these extra gaps are utilised as represented in the figure. The resistance to be measured, x, in this case bridges gap 3, whilst 1 and 2 are occupied by resistances whose ratio to one another does not differ from unity more than does the ratio of the resistance x to the total resistance of the slide wire A B.

The testing battery E and the galvanometer G are connected as shown, gap 4 being bridged by its link of negligible resistance. The slider S is adjusted until a balance is obtained on the galvanometer G. The scale reading d is then noted, and x is disconnected from gap 3 and connected instead across gap 4, 3 being in this case bridged by its conducting link. A fresh balance is then obtained, and the second scale reading $d1$ is noted, then $x = d1 - d$.

It is, of course, essential to this test that the value of the scale reading in ohms or fractions of an ohm resistance of that section of the slide wire bounded by such scale reading be known. If such knowledge be not immediately availab'e it may readily be attained by inserting a resistance of known value, such as $\cdot 1\omega$, in the place of x, and similarly obtaining readings d and $d1$ as before, then since $x = d1 - d$, $\cdot 1\omega = d1 - d$, and consequently the difference between $d1$ and d will give the number of scale divisions corresponding to $\cdot 1\omega$, or that difference multiplied by ten will give the number n corresponding to one ohm, so that our formula, to read directly in ohms, becomes

$$x = \frac{d1 - d}{n}$$

It is essential for the accurate conduct of this test that the conducting link and its concomitant connections should be massive, and of absolutely negligible resistance.

Thomson's bridge method of determining low resistances is a modification of the first described fall of potential method, and is represented diagrammatically in Fig. 45, where A B is a circuit, the resistance of a section x of which, lying between the points a and b is required, whilst B C is a standard slide wire of known resistance per unit of length, joined in series with it, and a battery E and key K. The contact resistance at B is not of any import in this test. $e\,f$, $e^1\,f^1$, are subsidiary resistances

making contact with A B and B C at the points *a b* and *c d*, through knife edges if possible, with a view to clear definition. G is a high resistance galvanometer,

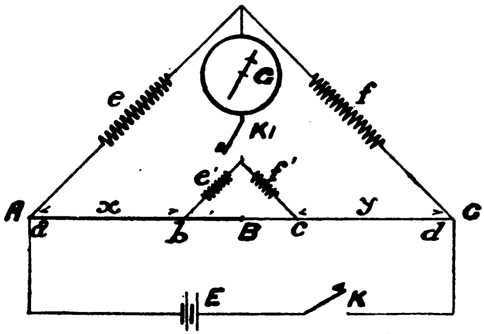


FIG. 45.

controlled by means of the key K1. The principle of the test consists in selecting two points *c* and *d* on the standard slide wire B C, such that a balance is obtained on the galvanometer when K and K1 are closed, then

$$e : f :: x : y, \text{ or } x = \frac{e\,y}{f}$$

The Post Office form of Wheatstone bridge may be adapted to Thomson's method of low resistance measurement, as indicated by Fig. 46, the lettering being the same as in Fig. 45. The INF plug is removed for this test, and a subsidiary resistance *f* of known value is introduced as shown, together with the extraneous key K. The remainder of the figure needs no explanation.

Müller's and Wallau's Method of Comparing very Low Resistances is indicated in Fig. 47, where A and B are the two low resistances to be compared, connected in series, and with the source of constant current E (a battery of accumulators answers the purpose). The termini of the resistances A and B as regards their precise value are represented by the points *a*, *b*, *c*, and *d*. G is a galvanometer, one side of which is permanently connected, as shown, to the junction of the standard resistances *r* and *r*1, which are made up in resistance box

form with accompanying plugs, to the value of 10,000 ohms apiece. All plugs are omitted in one and inserted in the other, thus leaving a total 'of 10,000 ohms con-

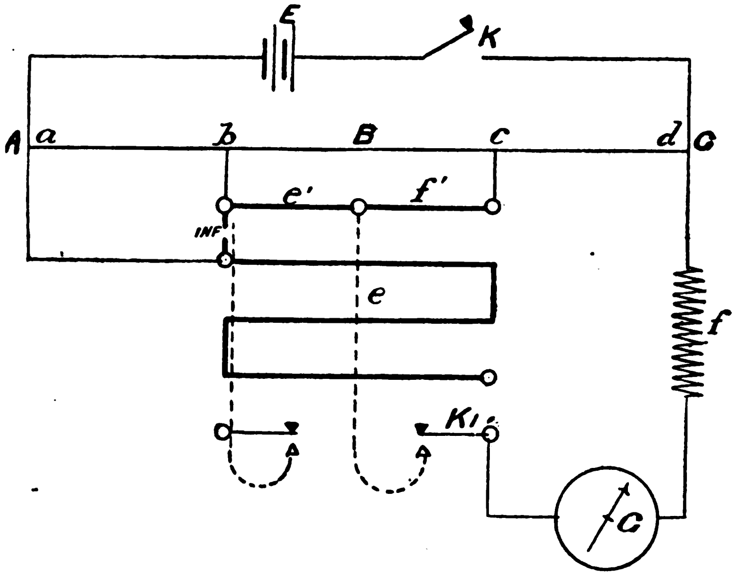


Fig. 46.

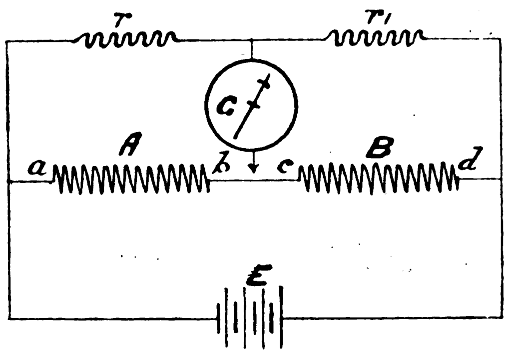


Fig. 47.

nected, which total must always be maintained in the the test, which is conducted as follows:—The galvanometer G has its free terminal connected in turn to the points a, b, c, and d, and is balanced to zero in each case by withdrawing plugs from the box r, say, and inserting them in $r1$ such that $r + r1$ still equals 10,000 ohms. Let the values withdrawn in this manner from r be respectively a, b, c, and d, corresponding to the balancing required when G is connected to each of these points in turn, then $B = \dfrac{Ad - c}{b - a}$

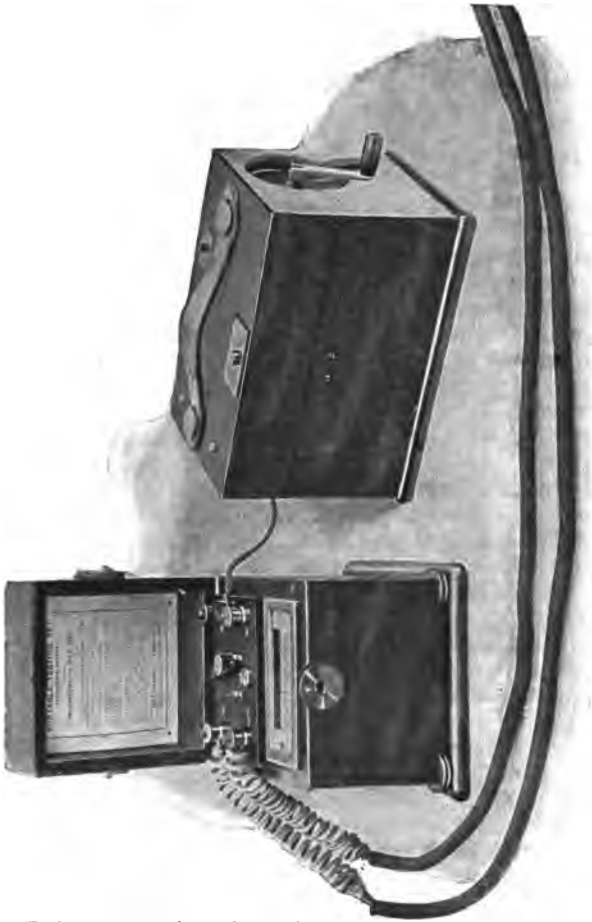
For the practical measurement of resistances over a range extending from zero to five megohms, Evershed's Ohm-meter is especially applicable, and has withstood the test of time. It is shown in general view in the accompanying illustration, and consists of two essential parts, viz., the ohm-meter proper and the generator. The former consists of an astatic system of magnetic needles delicately suspended at the centre or point of intersection of two coils placed at an angle of 45 degs. with one another. One coil (outer) is connected in series, and the other (inner) in shunt with the circuit containing the resistance to be measured. In the latter pattern of instrument the astatic needles are magnetised by the actual current from the generator, so that, by obtaining a mean of two readings consequent on turning the generator handle first in one direction and then in the other, the instrument may be employed with a fair degree of accuracy in the immediate neighbourhood of strong magnetic fields due to dynamos, etc., in addition to being, through its astaticism, independent of the earth's magnetic field.

The generator, which is contained in a separate case, consists of a special magneto machine capable of producing a range of voltages varying from 10 to 500 at a moderate speed imparted to it by means of a convenient handle, in either direction.

The instrument is direct reading, and only requires connecting up according to the directions supplied with it, and a subsequent rotation of the generator handle at a moderate speed.

To check the accuracy of an ohm-meter, it is best to first measure a resistance of convenient current-carrying

capacity by the ordinary bridge method, and then measure its resistance by ohm-meter, rather than compare with the bridge coils direct, in order to eliminate possible temperature errors due to heating of the coils.



Evershed Ohm-Meter Testing Set.

Before departing altogether from the resistance section of this series, we will briefly consider its near neighbour or reciprocal, in the capacity of :—

7. *Conductivity Measurement.*—It frequently happens, in dealing with conductors of various kinds, that we require to discover what is known as the "percentage conductivity," *i.e.*, the conductivity of the sample conductor under test, as compared with an exactly similar sample of absolutely pure copper, regarded as possessing a conductivity of 100. If my readers have met with many current specifications for electrical work they will in all probability have experienced the term "all copper used to have a conductivity of — %." This means that a margin of so much per cent. is allowed for impurities and other causes affecting the conducting power of otherwise pure copper.

A method of determining the percentage conductivity of any given sample consists in cutting off a suitable length, such as 100 feet, for example, and carefully determining its resistance in ohms, by means of the Wheatstone bridge method previously described. It is then weighed in a delicate scale pan, the resultant weight being reduced to grains. The temperature also is carefully observed at the time of making the test; then the

$$\text{percentage conductivity} = \frac{l^2 \times 22{\cdot}61}{w\,k\,r}$$

where l represents the length tested in feet.
" w " " weight " " grains
" r " " resistance in ohms.
" k " " temperature co-efficient.

The numerical values of k at various temperatures are given in tabular form in Kempe's "Handbook of Electrical Testing," and are reproduced herewith.

Co-efficients for correcting the observed resistance of pure copper wire at any temperature to 75° F., or at 75° F. to any temperature :—

Temp. in °F.	Co-eff.	Temp. in °F.	Co eff.	Temp. in °F.	Co-eff.	Temp. in °F.	Co-eff.
100	·9484	82·5	·9842	65	1·0214	47·5	1 0601
99·5	·9494	82	·9853	64·5	1·0225	47	1·0612
99	9504	81·5	·9863	64	1 0236	46·5	1·0623
98·5	·9514	81	·9874	63·5	1 0247	46	1 0634
98	·9524	80·5	·9884	63	1·0258	45·5	1 0646
97·5	·9534	80	·9895	62·5	1 0269	45	1·0657
97	·9544	79·5	·9905	62	1·0280	44·5	1·0668
96·5	·9554	79	·9916	61·5	1·0290	44	1 0679
96	·9564	78·5	·9926	61	1·0301	43·5	1·0690

Temp. in °F.	Co-eff.	Temp. in °F.	Co-eff.	Temp. in °F.	Co-eff.	Temp. in °F.	Co-eff.
95·5	·9575	78	·9937	60·5	1·0312	43	1·0702
95	·9585	77·5	·9947	60	1·0323	42·5	1·0714
94·5	·9595	77	·9958	59 5	1·0334	42	1·0725
94	·9605	76 5	·9968	59	1·0345	41·5	1·0736
93·5	·9615	76	·9979	58·5	1·0356	41	1·0748
93	·9626	75·5	·9990	58	1·0367	40 5	1·0759
92·5	·9636	75	1·0000	57 5	1 0378	40	1·0771
92	·9646	74·5	1·0011	57	1·0389	39 5	1·0782
91·5	·9656	74	1·0021	56·5	1·0400	39	1 0793
91	·9666	73·5	1·0032	56	1 0411	38·5	1·0804
90·5	·9677	73	1·0042	55·5	1·0422	38	1·0816
90	·9687	72 5	1·0053	55	1·0433	37 5	1·0828
89·5	·9697	72	1·0064	54·5	1·0444	37	1·0839
89	·9708	71·5	1·0074	54	1·0455	36 5	1·0851
88·5	·9718	71	1·0085	53·5	1·0466	36	1·0862
88	·9728	70·5	1·0096	53	1·0478	35·5	1·0873
87·5	·9738	70	1·0106	52·5	1·0489	35	1·0885
87	·9749	69 5	1·0117	52	1·0500	34·5	1·0896
86·5	·9759	69	1·0128	51·5	1·0511	34	1·0908
86	·9769	68·5	1·0139	51	1·0522	33·5	1·0920
85·5	·9780	68	1·0149	50 5	1·0533	33	1·0932
85	·9790	67·5	1·0160	50	1·0544	32 5	1·0943
84·5	·9801	67	1·0171	49·5	1 0556	32	1·0955
84	·9811	66·5	1·0182	49	1 0567	31·5	1·0966
83·5	·9821	66	1·0193	48·5	1·0578	31	1·0978
83	·9832	65·5	1·0204	48	1·0589	30·5	1·0990

Table of multiplying co-efficients for reducing the observed resistance of ordinary copper wire at any temperature to 60° Fahrenheit:—

Temp. F.	Co-eff.	Temp. F.	Co-eff.	Temp. F.	Co-eff.	Temp. F.	Co-eff.
90	·9392	76·5	·9661	63	·9937	49 5	1·022
89·5	·9402	76	·9671	62·5	·9948	49	1·023
89	·9412	75 5	·9681	62	·9958	48·5	1·024
88 5	·9421	75	·9691	61·5	·9969	48	1·025
88	·9431	74 5	·9701	61	9979	47·5	1·026
87·5	·9441	74	·9711	60·5	·9990	47	1·027
87	·9451	73·5	·9722	60	1·000	46·5	1·029
86·5	·9461	73	·9732	59·5	1·001	46	1·030
86	·9471	72 5	·9742	59	1·002	45·5	1·031
85·5	·9481	72	9752	58·5	1·003	45	1 032
85	·9491	71·5	·9762	58	1·004	44·5	1·033
84·5	·9501	71	·9772	57·5	1·005	44	1·034
84	·9510	70 5	·9783	57	1·006	43 5	1 035
83·5	·9520	70	·9793	56·5	1·007	43	1·036
83	·9530	69·5	·9803	56	1·008	42·5	1·037
82·5	·9540	69	·9814	55·5	1 009	42	1 038
82	·9550	68·5	·9824	55	1·010	41·5	1·039
81·5	9560	68	·9834	54·5	1·012	41	1·041

Temp. F.	Co-eff.	Temp. F.	Co-eff.	Temp. F.	Co-eff.	Temp. F.	Co-eff.
81	·9570	67·5	·9844	54	1·013	40·5	1·042
80·5	·9580	67	·9855	53·5	1·014	40	1·043
80	·9590	66·5	·9865	53	1·015	39·5	1·044
79·5	·9600	66	·9875	52·5	1·016	39	1·045
79	·9610	65·5	·9886	52	1·017	38·5	1·046
78·5	·9621	65	·9896	51·5	1·018	38	1·047
78	·9631	64·5	·9906	51	1·019	37·5	1·048
77·5	·9641	64	·9917	50·5	1·020	37	1·049
77	·9651	63·5	·9927	50	1·021	36.5	1·050

In some cases the diameter of the conductor in mils. is more readily obtainable than the weight of the sample tested. In such cases, the percentage conductivity $= \dfrac{l \times 1065{\cdot}6}{d^2\,k\,r}$ where l, k, and r represent the same quantities as in the previous equation whilst d is the diameter of the sample in mils, or thousandths of an inch.

When dealing with conductors of fine gauge in which the correct diameter is somewhat difficult to determine, it is far better to resort to the weight method, by means of which, given a fairly sensitive balance, great accuracy can be attained.

For rapidly conducting a large series of conductivity tests on conductors of various sizes, Messrs. Nalder Brothers have designed the composite apparatus shown in the accompanying illustration. Figure 48 represents a working diagram of the apparatus, which consists in the main, of a series of ten carefully calibrated standards a, b, c, &c., of 1ω, $\frac{1}{2}\omega$, $\frac{1}{4}\omega$, respectively, down to $1/512\omega$.

These are connected at one end to a common 'bus bar A, and at the other to individual studs on a circular double contact switch B, which connects one end of them, respectively with a galvanometer terminal 1, and a variable resistance switch C, the movable arm of which is connected to one of the main terminals X. S is an adjustable slider, working on the common 'bus bar D, which is connected to No. 2 galvanometer terminal. F and H are hinged steel knives enclosing the space of one metre between their respective edges. L is a metre scale, over which the slider S indicates. Galvanometer terminals 3 and 4 are connected to the 'bus bar A, and the knife F respectively. G is the high resistance galvanometer which, by means of the double switch J, can be connected across terminals 1 and 2, or 3 and 4, at will.

A differential galvanometer can also be used with this apparatus, the two windings being connected across 1, 2. and 3, 4 respectively. E is an accumulator, or cell, capable of giving a constant discharge rate of anything up to, say, 10 ampères.

The method of using this apparatus is as follows. A

(Copper Conductivity Apparatus, designed by Messrs. Nalder Bros., for rapid commercial work.)

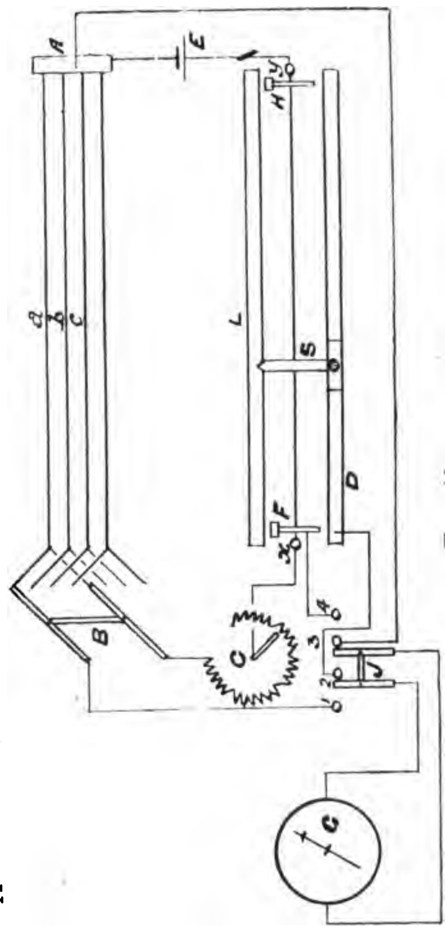


FIG. 48.

length of the conductor whose conductivity it is required to measure is stretched as tightly as possible, without actually "killing" it, between the massive terminals X and Y. The hinged knives F and H are then brought down into contact with it without exercising sufficient pressure to nick or cut the conductor. The galvanometer switch J is placed in position on 3 and 4, and the slide S brought nearly up to the right hand knife H. The resistance switch C, which to start with was in the "off" position, is then manipulated until the largest readable deflection is obtained on the galvanometer scale. The switch J is then manipulated so as to make contact with 1 and 2, and thus bring the standard wires into circuit; the double contact switch B is then turned until that standard is included in the circuit which gives the next largest deflection to that already obtained on the galvanometer scale. We will call this deflection *d*. The switch J is now brought to 3 and 4, and the slider manipulated until *d* is again obtained on the galvanometer scale; then note the scale reading *D* of the slider S. Switch off the current at C, and cut out the metre length of conductor by depressing both knives F and H simultaneously. This length should then be weighed, and its weight W in grains noted, then the percentage conductivity $= \dfrac{D\frac{1}{R}}{W}k$ where R is the value in ohms of the standard wire used, and k is a constant experimentally determined for the instrument.

When a differential galvanometer is used with this apparatus, the working is, of course, all effected to zero instead of to a given deflection *d*.

The apparatus is a very convenient one for rapid working, and saves considerable waste of material, as only one metre length of each sample is employed in the test.

We will now leave the subject of resistance and conductivity measurement for a time, and proceed to a consideration of another very important matter, viz.:—

(8) *The Determination of Electromotive Force.* Like the matters already dealt with, there are several methods of arriving at the E.M.F. existing in a circuit, all of

which are more or less suitable according to the instruments and apparatus available, and to the local conditions governing the test. We will deal with these various methods in turn, and, in all cases, the E.M.F. to be determined will be represented by a battery designated by the letter E. It may be mentioned that nearly all the tests for electromotive force consist in a more or less direct comparison of the E.M.F. to be measured with the known E.M.F. of a standard cell, Clark's standard, previously described, being the one generally adopted for the purpose.

The Equal Deflection method consists in connecting the standard cell Es Fig. 49, through an adjustable re-

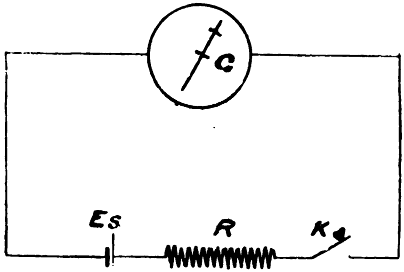


FIG. 49.

sistance R, and a key, K, with the galvanometer G. The resistance in circuit in this case, and, in fact, in all cases where Clark's standard cell is employed, should be sufficiently high to ensure that no appreciable current is taken from the standard cell, as otherwise polarisation is set up, and its E.M.F. falls from the constant value of 1.435 true volt at 15.5° C., thereby impairing the accuracy of the test. For this reason, the galvanometer G should be of the high resistance type (a Thomson reflecting instrument answers very well), and the resistance R should also have a fairly high value. The connections being made as illustrated in the figure, the key K is closed, and the deflection of the galvanometer needle observed and noted. K is then opened, and Es replaced by the battery E, the E.M.F. of which it is required to measure. K is then again closed, and R adjusted to R1 such that the original deflection is again obtained on the galvano-

meter, then $E = Es \frac{R1}{R}$ volts. This result will be sufficiently approximate for all practical purposes if the resistance of the batteries E and Es be so low as to be negligible compared with the resistances R and R1, and the resistance of the galvanometer G.

If a shunt S be employed with the battery E, or shunts S and S1 for both measurements, then the formula becomes

$$E = Es \frac{R1 \frac{G + S}{S}}{R} \quad \text{and} \quad E = Es \frac{R1 \frac{G + S}{S}}{R \frac{G + S1}{S1}}$$

respectively, S and S1 being the shunts employed with E and Es respectively. It is essential in employing the last two formulæ that the resistances of the galvanometer, shunts, and batteries are so small compared with R and R1 as to be negligible. In such case it is needful to employ a more stable standard Es, such as a Daniell cell yielding 1.079 volt, than Clark's type, in conjunction with a galvanometer of comparatively low resistance.

The equal resistance method is somewhat similar to the foregoing, but necessitates a knowledge of the internal resistances of the standard cell Es and the cell E under test respectively, unless these resistances be so low in value as to be negligible compared with R and R1.

The connections for the test are the same as in Fig. 49, The standard cell is first placed in circuit, and its deflection *d* noted on depressing K. Es is then replaced by the cell E under test, and the resistance R is adjusted until the total resistance in circuit is the same as in the preceding case, and the second deflection *d*1 is also observed, then the electromotive force of the cell under test

$$E = Es \frac{d1}{d}$$

The total resistance of the circuit mentioned above includes, of course, the resistance of the respective cells, the galvanometer, and the resistance R, but if the internal resistances of the two cells be very low compared with the other resistances in the circuit, they may be neglected with sufficiently approximate accuracy to the subsequent results.

Wheatstone's method may also be noted by the same

Fig. 49; the standard cell Es is connected with the galvanometer G through a resistance R, and the consequent deflection d noted. The resistance R is then increased to **R** + r, R and r being as nearly equal as it is possible to make them, and a second deflection $d1$ is obtained. The E.M.F. under test E is then connected in circuit in place of the standard cell Es, and, by varying the resistance R to R1, the same deflection d as was obtained in the first instance is reproduced. R1 is then increased to R1 + $r1$ such that the second deflection $d1$ is reproduced on the galvanometer; then the E.M.F. of E = Es $\cdot \frac{r1}{r}$ volts.

Poggendorff's method for the determination of electromotive force differs somewhat from the foregoing tests, and is represented in Fig. 50, where E is the E.M.F. to be determined, R the main variable resistance, r a subsidiary resistance, only required when the resist-

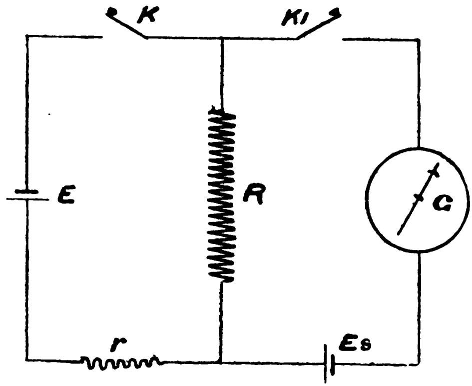


Fig. 50.

ance of E is unknown, Es a standard cell, G the galvanometer, and K, K1 ordinary circuit keys. If Es be a Clark's cell, an additional resistance of some 10, 000ω is required in series with it and the galvanometer, to prevent an excessive passage of current from it into the circuit, but, if the cell be of a more stable type, such as the Daniell, for instance, no such auxiliary resistance is required, nor is its presence indicated in the figure.

The mode of procedure is as follows. Let us suppose in the first instance that we know the resistance of the battery E, then r is omitted, and K and K1 being closed, R is adjusted until a balance or zero reading is obtained on the galvanometer G. Then the required E.M.F. $E = Es \frac{R + Re}{R}$ volts, where Re is the resistance of the source of E.M.F. (E.). If, on the other hand, Re be an unknown quantity, include the subsidiary resistance r in the circuit, and proceed as before to adjust R with K and K1 closed, until no deflection results upon the galvanometer. Next vary r to $r1$, and R to R1, until a balance is again obtained with K and K1 closed; then the E.M.F. to be determined, $E = Es \frac{(r - r1) + (R - R1)}{R - R1}$ volts.

The variable resistances R and r, in this test are conveniently provided by the proportional and adjustable arms of a Wheatstone bridge, the connections in such case being as indicated by Fig. 51, R being unplugged in the adjustable arm, and r, if needed, in the proportional arms.

As will readily be conceived from the attendant dia-

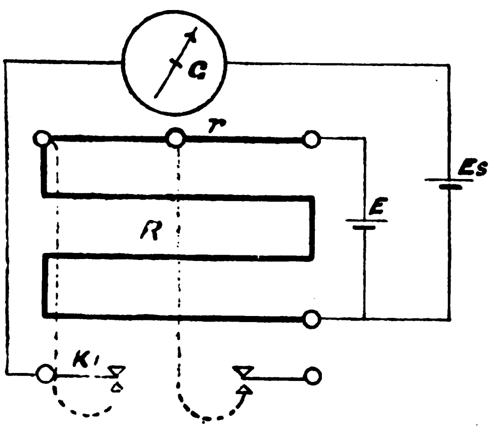


Fig. 51.

grams of connections, this method consists in opposing one E.M.F. (under test) to the other (standard), and so adjusting the resistances in circuit that these electromotive forces exactly balance one another, and no current, in consequence, flows through the galvanometer.

Kempe's method of determining electromotive forces is somewhat ingenious and simple in its application. Its two phases are represented by diagrams A and B, Fig. 52, respectively. In the first instance, the standard E.M.F., Es, and the E.M.F. under test, E, are opposed to one another, and connected with the terminals of a Thomson reflecting galvanometer; the resulting deflection *d*, due to the preponderance of one E.M.F. over the other, is duly noted. The electromotive forces are then, as indicated in diagram B, connected up in series to assist one another, and the resultant deflection being rather large, a shunt *s* is introduced across the terminals of the galvanometer G. The introduction of this shunt, according to the law of divided circuits, materially lowers the total resistance of this particular circuit which we are now

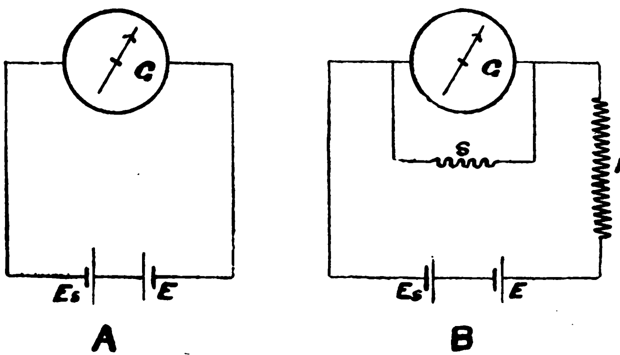


Fig. 52.

dealing with, and, to cope with this decrease, what is known as a "compensating resistance," R, is introduced into the circuit, R being of such a value as to render the total resistance of the circuit the same as it was before the introduction of the shunt *s*.

The second deflection *d*1 is also duly noted, together

with the value of the shunt, and the multiplying power of the latter, m, having been obtained from the aforementioned formula $\frac{G + s}{s}$ we have, as the formula for calculating the required value of E, $\frac{Es}{E} = \frac{m\,dl + d}{m\,dl - d}$.

Lumsden's or Lacoine's method, so-called from the fact that both gentlemen named devised this system independently of one another at or about the same time, is represented diagrammatically in Fig. 53.

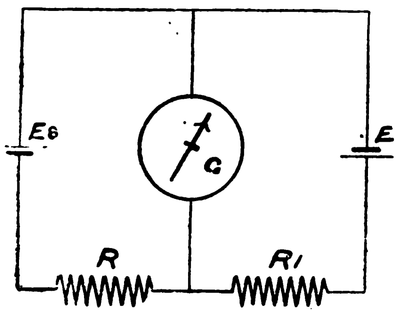


Fig. 53.

Es and E represent, as before, the standard and E.M.F. under test respectively, G the galvanometer, and R, R1 adjustable and fixed resistances respectively. The two electromotive forces are connected in series as shown, and R is adjusted until a balance is obtained on the galvanometer. Then the respective electromotive forces Es and E will bear the same proportion to one another as do the resistances R and R1, or $E = \frac{Es\ R1}{R}$.

Before proceeding with a description of any further tests for the determination of electromotive force, I must digress for a moment to describe a modification of the sets of plug resistances as usually constructed in the Wheatstone bridge form of instrument. The modification alluded to consists of a species of extended slide wire;

it is obviously impossible, with the ordinary stretched slide wire, to command a resistance of any magnitude between its extremities, without producing it to an enormous and therefore practically inconvenient length. The modification consists of a series of resistance coils, *a*, *b*, *c*, etc., Fig. 54, connected to metallic blocks as shown,

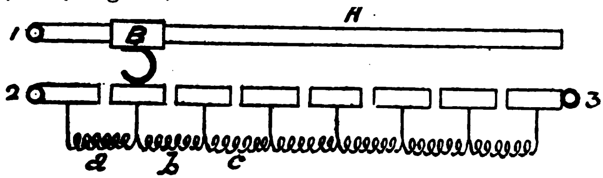


Fig. 54.

but, instead of being manipulated, as in the case of the Wheatstone bridge, by plugs, they are cut in or out of circuit by a sliding contact B, working along a 'bus bar A, so that any required resistance, within the limits of the apparatus, may be inserted between terminals 1 and 2 by moving the slider B along the bar without, at the same time, disturbing the value of the total resistance between terminals 2 and 3, a condition sometimes required in testing. This apparatus may conveniently be arranged in circular form, with a radial contact slider.

Having described this modification, which we shall require very shortly, we will now proceed to deal with Fahie's method of determining electromotive forces. This is essentially a combination method for measuring simultaneously the E.M.F. and internal resistance of a given battery, and is an adaptation of Poggendorff's and Mance's respective methods for these determinations, both of which have already been singly dealt with in the preceding paragraphs.

Fig. 55 represents a diagram of the connections for the test, in which *a* and *b* are the resistances on either side of the slider B in the apparatus depicted in the foregoing figure; *c* is an adjustable resistance, and G the galvanometer. E and Es are the battery under test and the standard respectively, whilst K is an ordinary circuit key employed to connect the two junctions, as shown.

The mode of procedure is as follows:—K being open,

the resistance c is manipulated until a balance is obtained on the galvanometer G. When such a balance has been obtained, the key K is manipulated in conjunction with the slider B until the latter is brought to such a position on the slide resistance a b, that the manipulation of K has no effect upon the resultant galvanometer deflection, then the resistance R of the battery E $= \frac{a\ c}{b}$, and the required electromotive force

$$E = \frac{Es\ (c + b)}{b}.$$

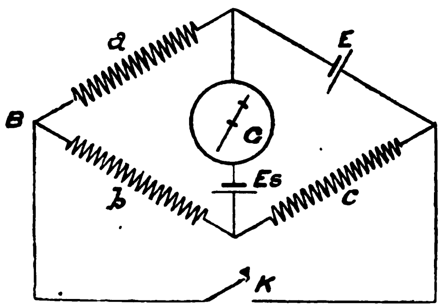


FIG. 55.

What is known as the Potentiometer Direct Method of determining electromotive force also involves the use of a slide resistance such as that described above. The connections for this test, which is an extremely simple one, are represented in Fig. 56, where a b represent the two resistances on either side of the slider B as

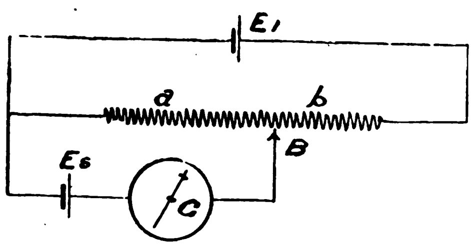


FIG. 56.

before, E1, a cell of constant electromotive force, Es the standard cell, and G the galvanometer.

Es is first connected up, as shown, and the slider B manipulated until no deflection results upon the galvanometer G. Note the resistance *a*, substitute E, the battery or E.M.F. under test, for Es, and repeat the operation, obtaining a second value *a*1; then $E = \frac{Es\, a1}{a}$

The Measurement of High Potential Differences.—There are several methods of ascertaining the E.M.F. or P.D. of a current when the latter is much above the normal, as in high tension work, for instance, of which the following is probably the most satisfactory.

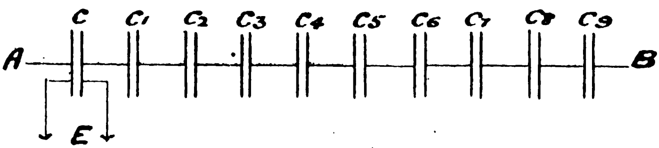


FIG. 57.

Let it be required to know the E.M.F. between the points A and B, Fig. 57; a number of equal condensers, *c*, *c*1, *c*2, etc., are connected in series between the points A and B, and the electromotive force E between the terminals of one of them, *c*, is ascertained by any of the usual methods, and multiplied by the number of condensers in the series.

Departing from the subject of electromotive force determination, we come to the next important item on our list of electrical measurements, viz.—

(9) *The Determination of Current Strength.*

One of the most direct methods for the determination of current strength in ampères consists in passing the current to be measured through a Siemen's electro-dynamometer, the construction and principle of which useful instrument we will now proceed to discuss.

Referring to Fig. 58, if we have two rectangular circuits A B C D, *a b c* D, one lying in a plane at right angles to the other, and connected in series at D, as shown, and, moreover, if one of the rectangles *a b c* D

be fixed, and the other suspended by a frictionless suspension as indicated in the figure, and a current be passed through the system by way of the terminals 1

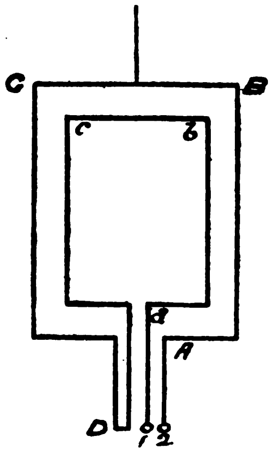


Fig. 58.

and 2, it is obvious, from certain well-known laws governing the action of neighbouring currents upon one another, that the movable rectangle A B C D will be attracted on one side and repelled on the other, and will, in consequence, tend to set itself in the same plane with the fixed rectangle *a b c* D, as represented in the figure. From the same laws it follows that this force, tending to produce motion of the movable rectangle A B C D, varies as the square of the current, and it is this principle, practically applied, which constitutes the Siemen's electro-dynamometer.

The instrument, as commercially constructed, is represented in the accompanying illustration, and consists of a fixed composite coil, composed of a few turns of thick wire, and a number of turns of thin wire. These two coils are connected together at one end, and to a common terminal which is the centre one of the three indicated in the figure. The remaining ends of the thick and thin coils are brought respectively to the two outer terminals, the object of the two coils being to increase the

effective range of the instrument according as to whether the current to be measured is large or small. The fixed coil, which corresponds with *a b c* D, Fig. 58, is supported on a suitable stand as shown, and is surrounded by a stout wire rectangle, lying in a plane at right angles to it, and suspended at its upper extremity from a thumb-

Siemen's Electro-Dynamometer for Current Measurement.

screw by means of a thin fibre running through the centre of a delicate spiral spring, which is also rigidly attached both to the rectangle and to the aforementioned thumb-screw. Superimposed upon these intersecting coils is a horizontal graduated dial, the periphery of which is divided into degrees, and around the outer edge of which, between the limits of two stops placed a short distance apart, and embracing at their centre the zero, or 0° point of the scale, plies an index finger, also rigidly attached to the movable coil. A second radial index attached to the thumb-screw also indicates upon the circumference of the scale, whilst three levelling screws and a suitable level or plumb-line complete the apparatus. Electrical connection with the movable coil or rectangle is made by means of two mercury cups, into which its lower extremities dip.

The mode of usage is as follows:—The apparatus having been set up and levelled until the movable coil is free to move in either direction, but remains stationary with both indices at zero, the current to be measured is passed through by way of one pair of terminals or the other, according to its probable value, and a deflection of the movable coil until checked by one of the stops is the result. The thumb-screw at the top is then turned in the opposite direction until the pointer or index attached to the movable rectangle is brought back to zero by the consequent torsion of the spiral spring. The angle through which the radial pointer has been turned to secure this result is then read off upon the horizontal dial, and the current passing is indicated upon a table of degrees and corresponding currents specially prepared for the instrument. This table is constructed by the manufacturers in the first instance by passing a current of known value through the instrument, and noting the number of degrees of torsion required to bring the movable index to zero. When this has been ascertained, the remainder of the table can be deduced by simple rule of three.

As may readily be imagined, the electro-dynamometer is most accurate when used for large currents, which require a considerable degree of torsion to counteract their deflective effects upon the movable rectangle, as in such cases the percentage of error is very small compared with that attendant upon the measurement of correspondingly small values.

The direct deflection method of current measurement is a comparatively simple one, and depends for its accuracy on the corresponding definition by the observer's eye, of the galvanometer readings. It involves the employment of a low resistance galvanometer, the resistance of which is known, a standard cell or accumulator from which a current equivalent to that to be measured can be taken without disturbing its constancy, and a variable resistance of sufficient dimensions to carry the current under test without appreciable heating. The resistance of the standard cell must either be known, or of so small a value as to be negligible in calculating subsequent results.

The galvanometer is first joined up in the circuit through which is flowing the current which it is required

to measure, and its deflection duly noted. It is then disconnected from the circuit, and inserted in simple series with the standard cell and variable resistance, and the latter is adjusted until the same deflection is obtained on the galvanometer as before, which is due evidence of the passage of an equivalent current. Then by Ohm's law, the current in each case is equal to the electromotive force of the standard cell in volts, divided by the total resistance of the latter circuit in ohms. If unknown, the E.M.F. of the standard cell can be ascertained by one of the methods already described for the determination of electromotive force.

Expressed as a formula, let E be the E.M.F. of the standard cell,

Let C be the current which it is required to measure.
,, Rg ,, ,, resistance of the galvanometer.
,, R ,, ,, variable resistance (in circuit).
,, Rc ,, ,, resistance of the standard cell (if required).

$$\text{Then } C = \frac{E}{Rg + R + Rc}$$

The difference of potential deflection method for the determination of current strength is indicated in Fig. 59, where *a b* is a low-resistance introduced into the path of

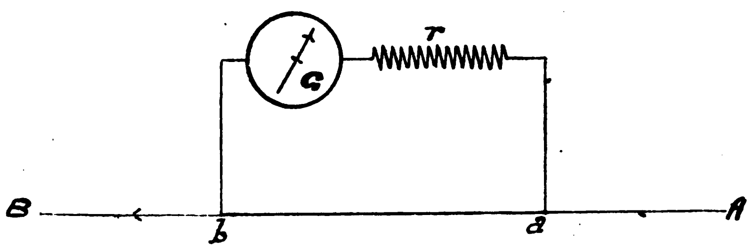


FIG. 59.

the current to be measured, which is flowing from A to B, as indicated by the arrow heads, G is a high resistance Thomson galvanometer, and *r* an auxiliary resistance, also of high value, the combined resistance of G and *r* being such that they do not materially influence the value of

the current to be measured, which we will call C, by their introduction in derived circuit, as shown.

The galvanometer being connected to the points *a* and *b*, as indicated in the figure, a deflection *d* results from the difference of potential between these points; this deflection is noted, and the galvanometer and its attendant resistance are then disconnected from *a b*, and connected instead to the terminals of a standard cell, the electromotive force, Es, of which is known. A second deflection, *d*1, is thus obtained, then the current to be measured, $C = \frac{Es\ d}{R\ d1}$ where R is the value of the low resistance *a b* in ohms or fractions of an ohm.

The difference of potential equilibrium method is somewhat similar to the above, and is represented in diagram

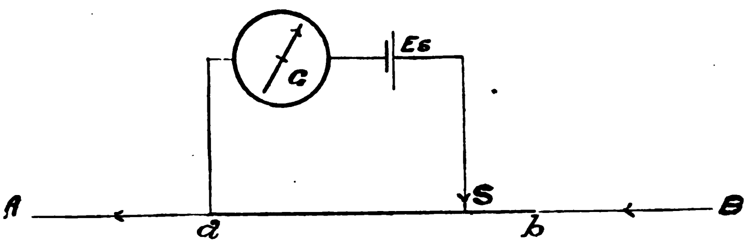


FIG. 60.

by Fig. 60. The current to be measured flows from B to A as before, but in this case *a b* represents a slide wire resistance of which S is the contact slider. The galvanometer G and standard cell Es are connected as shown, such that the current from the standard cell Es tends to oppose that to be measured, which, as before stated, is flowing from B to A in the direction indicated by the arrow heads. The slider S is adjusted until no deflection results upon the galvanometer G, then the required current C is equal to the E.M.F. of the standard cell Es, divided by the resistance of the slide wire between *a* and S, which we will call R, or, expressed as a formula, $C = \frac{Es}{R}$

From this it will be seen that the ohmic resistance of

any given length of the slide wire, in terms of the divisions on its scale, must be known.

Kempe's bridge method is a modification of that devised by Major Cardew, R.E., but since the latter method involves the use of a specially constructed galvanometer, we will not touch upon it here.

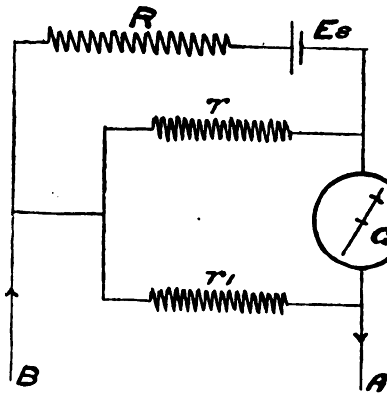


FIG. 61.

Kempe's method is indicated in Fig. 61, where the current to be measured, C, flows from B to A, as before. R is a variable resistance, and Es a standard cell or accumulator, from which a current can be taken, not necessarily as large as C, however. r and $r1$ are also resistances of fixed value; the resistance of r as compared with $r1$ determines the value of the current which will be taken from the standard cell Es as compared with C, the current to be measured.

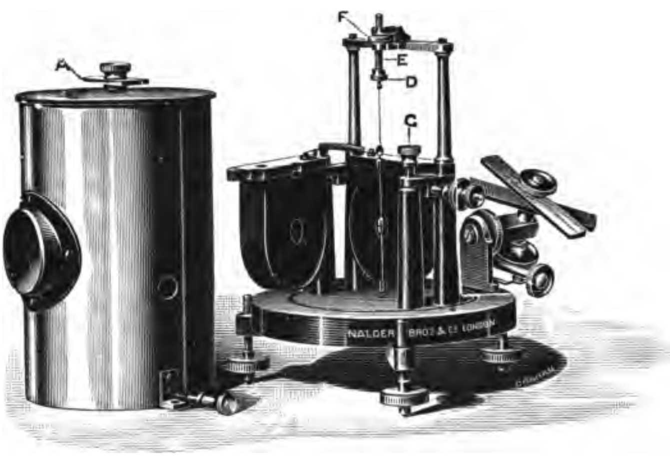
The connections being as shown in the figure, R is adjusted until no deflection results upon the galvanometer G, then $C = \dfrac{Es\ r}{r1\,(R + r)}$.

From the determination of current strength, we next pass on to—

(10) *The Measurement of Electrostatic Capacity,* which usually involves a comparison of the electrostatic discharge from the condenser under test with that from a

standard condenser of known capacity, either directly or indirectly. Before proceeding further, however, I would deal in brief with a special form of galvanometer, adapted for the measurement of such transient currents as those involved in the electrostatic discharge of a condenser of large capacity, such as a long section of submarine cable, for example. Such a discharge current lasts for a perceptible period of time, whereas the momentary discharges from condensers of low electrostatic capacity are comparatively brief, and may readily be compared by the transient swing of an ordinary Thomson reflecting galvanometer. Nevertheless, as the reader may have occasion to deal with large electrostatic capacities in one or another connection, a knowledge of the construction and principle of what is known as the "ballistic galvanometer" will not come amiss.

The ballistic galvanometer, as commonly constructed, is shown in the accompanying illustration, and is exactly similar to an ordinary Thomson reflecting galvanometer in all respects except the suspended system, the detailed construction of which is represented in diagram in Fig. 62, where *a b* represents the ordinary aluminium axis, pass-



The N.C.S ' Ballistic Galvanometer, by [illegible] Bros.
Stock Winding 1,000 ohms.

ing through the centre of a split cylindrical magnet A, shaped somewhat like a thimble; a transverse section along the line *c d* is shown at B. These magnets, with their semi-cylindric poles *n s*, replace the little watch-spring magnets in the Thomson instrument, and may be mounted, two with their like poles opposite, in the centre of each coil, and two others immediately outside the coil above and below, as represented in the complete illustration above, or in any other similarly suitable manner, the object of the cylindrical form given to the magnets being that they may offer as little resistance to motion as possible in their passage through the surrounding air. As a matter of fact, in practice, the motion of the needle does not commence until the current causing it has ceased.

When, as is often the case, the number of oscillations made by the needle of a ballistic galvanometer in a given time, is required, it can be obtained by fixing the eye

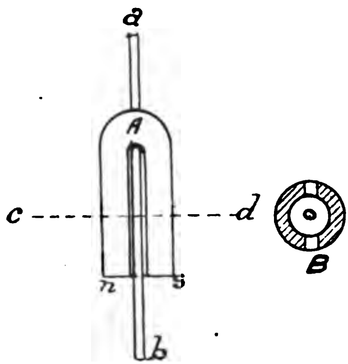


Fig. 62.

upon a certain point on the galvanometer scale within the limits of the deflection, and counting the number of times the reflected spot of light passes that point, whilst travelling in the *same direction*, during the time stated.

For the mathematical and mechanical proofs underlying the action of the ballistic galvanometer, the reader is referred to Kemple's "Handbook of Electrical Testing."

To proceed, however, with the more immediate subject-

matter of this section, viz., the determination of electrostatic capacity. For the majority of the tests about to be described in this connection, the ordinary Thomson reflecting galvanometer is admirably suited, more especially if fitted with the usual damping device to check the more or less irresponsible swings due to the sudden condenser discharges, etc.

The simplest method for the determination of electrostatic capacity is known as the direct deflection method, and is represented diagrammatically in Fig. 63, where G represents a Thomson galvanometer, which may or may not be provided with a shunt across its terminals, according to whether the discharges to be compared are small or large; it is therefore to a great extent dependent upon the battery power E used, but, in any case, a shunt will be found useful, and should be included among the apparatus for the test, although it has been omitted from the figure for the sake of clearness. K represents Lambert's discharge key, previously described and illustrated, whilst C is the standard condenser of known capacity, for which is ultimately substituted the electrostatic capacity or condenser, whose value it is required to determine, such as a length of cable, for example.

The *modus operandi* is as follows:—K2 is first depressed for a definite period, such as 30 seconds or more, in order to charge the standard condenser C to saturation.

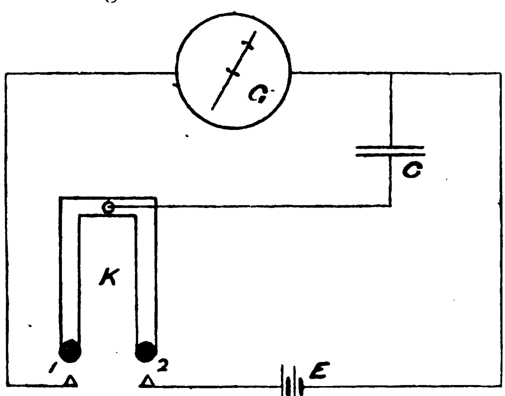


Fig. 63.

It is then released, and K1 depressed in its turn; this action serves to discharge C through the galvanometer, the magnitude of the initial swing of the needle of which should be noted; we will call it d. The standard condenser C is then disconnected and replaced by the condenser under test, which in the case of our length of cable, for example, would consist of one end (the other being free), and the earth surrounding it, such as the armouring or lead sheathing, if it possessed any, or the water in a tank if the cable be submerged therein. The operations with K1 and 2 are then repeated, and a second deflection or swing $d1$ is obtained.

Then the capacity under test : C : : $d1$: d

or, the required capacity $= \dfrac{C\ d1}{d}$

If a shunt be used in either of the above operations, the necessary multiplication of the observed deflections by the now well-known formula $\dfrac{G + S}{S}$, must, of course, be effected.

Gott's method is illustrated in Fig. 64, where C and C1 represent the standard and the condenser under test respectively, E the battery, K a Webb's discharge key previously described, K1 an ordinary circuit key, G the galvanometer, and r, $r1$ two resistances giving a fairly large

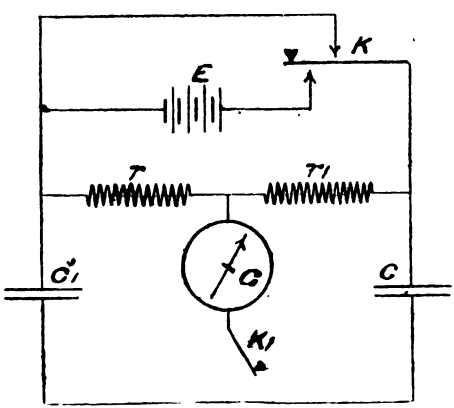


FIG. 64.

range of proportional adjustment, with attendant accuracy of comparison. r and $r1$ are first adjusted as nearly as possible in the proportion of C to C1; K is then depressed, and held in that position by means of its detent, thus charging both C and C1 simultaneously in series, from the battery E. After a definite period as before, K1 is closed, and, if a deflection be obtained on the galvanometer G, both keys are released, and the respective condensers short-circuited, or put to earth as the case may be, in order to dissipate their respective charges. r and $r1$ are then readjusted, and the operation repeated until no deflection results upon the galvanometer when K1 is depressed.

This being the case, $C1 = C \dfrac{r1}{r}$

The proportional resistances r and $r1$ may conveniently be arranged in the form of a slide resistance of some 10,000 ohms, the galvanometer being connected to the slider.

Thomson's method of capacity measurement is very similar to the foregoing, the connections being represented in Fig. 65, where C and C1 represent the standard and condenser under test respectively, E the battery, G the galvanometer, and 1, 2, 3, 4, and 5 simple circuit

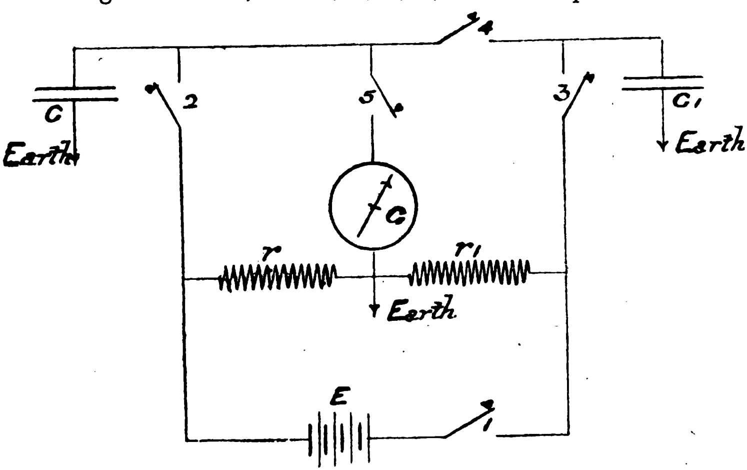


FIG. 65.

keys, all of which may be dispensed with by employing a combination key designed by Mr. Lambert, which combines all the necessary movements upon one universal base.

The method of conducting the test is as follows:—Key 1 is first closed, thus connecting the battery E through the resistances r and $r1$ to earth. Keys 2 and 3 are then closed simultaneously (by a single movement in Lambert's key) for a definite period, in order to charge the two condensers C and C1; the two Keys 2 and 3 are then opened, and Key 4 is closed also for a definite period in order to allow the respective charges in condensers C and C1 to mix. Finally Key 5 is closed, and, if a deflection ensues, the ratio of r to $r1$ is varied, and the same operations repeated until no deflection results upon the galvanometer when 5 is closed, then $C1 = C \frac{r}{r1}$

What is known as the *Divided Charge method* for the measurement of electrostatic capacity is represented in diagram by Fig. 66, where E represents the charging

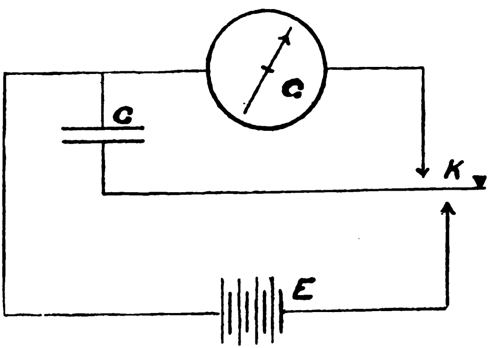


Fig. 66.

battery as before, G the galvanometer, C the standard condenser, and K a Webb's discharge key. C is first charged by depressing K on to the lower contact for a definite period. K is then released, and makes contact with the upper stud, thus discharging C through the galvanometer G. The resulting deflection or throw d is

noted, and C is again charged by depressing K on to its lower contact for a similar period; at the end of the charging time the lever of K is set by means of its detent in the centre or insulated position shown in the figure, and C1, the condenser under test, is substituted for the battery E, care being taken not to touch the lever of K (the safer course would be to arrange C1 in a parallel circuit so that it can be substituted for E by means of a plug or other well-insulated switch). K is then again depressed, thus connecting the two condensers and allowing a consequent division between them of the initial charge.

This connection is left on for a definite period, as usual, and the standard condenser C is then again discharged by releasing K, so that it makes contact with the upper stop, and the second deflection $d1$ is noted,

then $C1 = C \frac{d - d1}{d1}$

The familiar name of Siemens is associated with three tests for the determination of electrostatic capacity, the first of which, known as Siemens' Diminished Charge method, is somewhat similar to the foregoing divided charge method, and possesses the attendant advantage of being applicable to the measurement of a large capacity by comparison with a standard condenser of small capacity.

The connections for the test are the same as indicated in Fig. 66, with the exception of an additional short circuit key, which must be introduced across the terminals of the galvanometer G. The mode of procedure is as follows:—Referring to Fig. 66, K is first depressed, thus charging the standard condenser C for the usual period; it is then released, and the discharge deflection d noted. K being then set at "insulate," as before, the parallel circuit, including C1, is brought into connection with E and charged for a like period. E is then cut out of circuit, and the standard condenser charged from C1 for the same period, and subsequently discharged, the galvanometer short circuit key being closed meanwhile. This charging of C from C1, and subsequent discharging through the short circuit key, is repeated for a given number of times, x, the charge remaining after each discharge, being less and less, until, at the x th. discharge,

the short circuit key is opened and the galvanometer G thereby introduced into the circuit. A second deflection $d1$ is thus obtained, then $C1 = \dfrac{C}{x\sqrt{\dfrac{d}{d1}}-1}$

For great accuracy in this test it is necessary that all apparatus should be well insulated to minimise leakage, and that the charging and discharging be effected with as small a time interval as possible.

Siemens' Loss of Charge Discharge method for the determination of electrostatic capacity consists in comparing the total discharge from the condenser under test with that discharge which takes place after the initial charge has been dissipating itself for a stated period through a known resistance of high value connected across its terminals.

As before, Fig. 66, with the single addition of a high resistance, usually some hundreds of megohms, across the terminals of C, which, in this case, denotes the condenser under test, will serve to explain the system. K is first depressed to charge C for the usual period, at the end of which it is immediately discharged by releasing the lever on to the upper contact, giving a discharge deflection or throw *d*. It is then depressed to charge again for the same length of time, at the end of which the lever of K is freed to the "insulate" position for a given period, say 30 seconds, during which time C will discharge itself in part through the high resistance which we will call R. At the end of the stated interval or number of seconds, S, the lever of K, is again released to discharge, and the resulting throw $d1$ is noted, then $C = \dfrac{S}{2.303 \text{ R} \log \dfrac{d}{d1}}$.

Siemens' Loss of Charge Deflection method is somewhat similar to the foregoing, and is represented in Fig. 67, where C is the condenser under test, connected at will for charging purposes to the well-insulated battery E, by means of the key K. G is a galvanometer also connected with the terminals of C through a high resistance R, which, as before, runs into megohms. The test is conducted as follows:—K is first closed, thus charging the condenser C, and producing a deflection *d* on the

galvanometer G, due to the full potential of the charging battery. K is then opened after a suitable charging period has elapsed, and the deflection on the galvano-

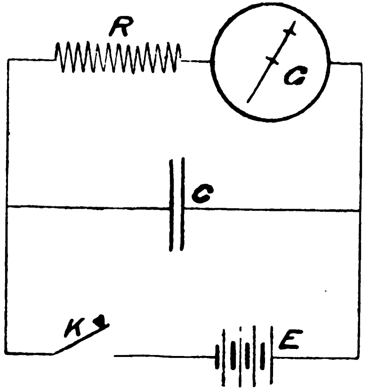


FIG. 67.

meter gradually falls owing to the discharging of C through the resistance R. The reduced deflection $d1$ at the end of S seconds from the commencement of the discharge is noted, then $C = \dfrac{S}{2.303 \text{ R} \log \dfrac{d}{d1}}$ as before.

In both the above tests C is in microfarads, S in seconds, and R in megohms.

Having thus far dealt with the elementary principles for the practical determination of the four fundamental electrical quantities, viz., Resistance, Electromotive Force, Current, and Capacity, we will now proceed to discuss one or two modifications and combinations of the foregoing methods, together with the apparatus necessary for their conduct, which are applicable to certain branches of electrical work.

Cable testing, in its many and varied forms, probably calls for the largest combination of electrical tests to discover its various qualities before being put on the market, and after being fixed or laid in position, in order to ascertain if it is suitable for the work it is intended to

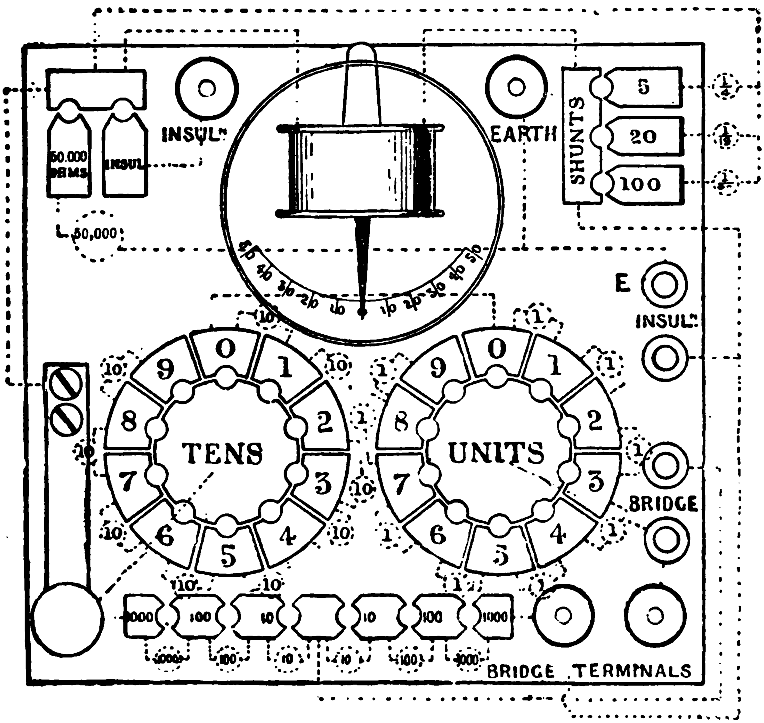
perform in the transmission of electrical energy from one point to another.

Electric cables and wires are tested for insulation resistance, electrostatic capacity, ohmic resistance, and, in the case of high tension work, for resistance to disruptive discharge, both at the factory during manufacture and by the purchaser when fixed in position, before absolutely putting them to work, and several very useful combinations of apparatus have been designed, with a view to including two or more of these various tests, and the switches, shunts, resistances, etc., necessary to their manipulation upon one universal base for the sake of portability and general convenience. Of these special combinations we will select two, and deal with them in turn as a pattern upon which are moulded the remainder of their species.

The Silvertown Portable Testing set, a most popular

Silvertown Portable Testing Set, made by the I R.G.P. &c. Co., Ltd.

combination with electrical engineers generally, is depicted *in toto* in the accompanying block, together with a general diagram of the connections involved in its construction.



General arrangement showing all connections.

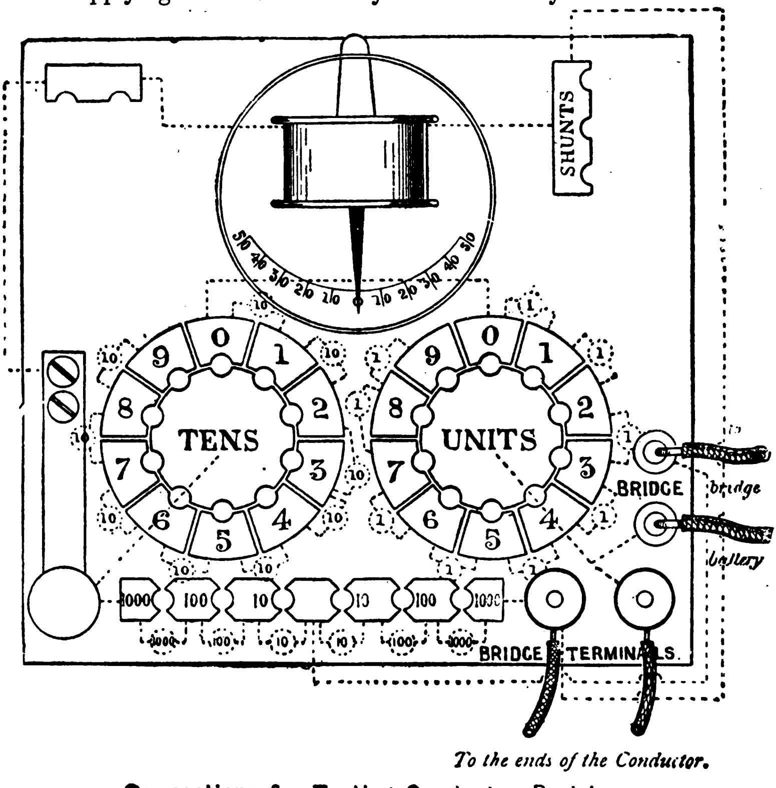
It consists in the main of a small dial pattern bridge, and horizontally pivoted galvanometer, together with the necessary shunts and circuit key, plug switches, etc., necessary to render it adaptable at will to the measurement of both conductor and insulation resistance of all sorts and conditions of electrical circuits. The whole of the necessary detail is mounted on an ebonite base piece, let into the upper portion of a strong, serviceable,

polished wood base, provided with a sunk cover, specially lined and padded to receive the plugs and other loose portions of the apparatus when not in use. By an ingenious attachment, the act of closing the lid raises the galvanometer needle from its pivot, and secures it from injury consequent on rough handling. The makers also supply a second convenient box containing the batteries necessary for the conduct of the aforementioned tests, viz., a set of three low resistance Leclanché elements for the measurement of conductor resistance by the bridge method, where an appreciable current is required in the circuit, and, in addition, 36 small Leclanché elements, capable of yielding a total voltage of 55, on open circuit, for the measurement of insulation resistance by the previously described direct deflection method. No appreciable current can be taken from these cells without materially lowering their voltage, but, in the test under consideration, such a course is not necessary, the main object being the provision of a sufficient electromotive force, or difference of potential between the conductor of the cable under test and earth.

As will be noted from the accompanying illustration and diagram of connections, there are two sets of dial resistances, tens and units respectively, in the variable arm of the bridge, whilst the proportional arms run in thousands, hundreds, and tens respectively. The connections between the battery and testing set consist of flexible leads provided with ebonite capped plugs, which fit into holes to the right of the set, marked INSULn. and BRIDGE respectively, according to the test which it is required to make. There are three shunts, so marked in the diagram, giving multiplying powers of 5, 20, and 100 respectively, according to which of them is introduced into the circuit by inserting the plug in its corresponding position. The plug blocks marked 50,000 ohms and INSULn. are used when making an insulation test, as will be described presently, whilst the upper pair of terminals are for insulation, and the lower pair for conductor resistance measurement respectively. We will take the two tests of which this compact set is capable in turn, and deal with the mode of procedure in either case. Before proceeding further, however, I may mention that a controlling magnet for the galvanometer is

provided in swivel form, countersunk into the side of the containing case as shown, and its effect is such that, with its north pole uppermost, the galvanometer is most sensitive, and *vice versâ*.

To proceed, however, with the Wheatstone bridge method of resistance measurement by this apparatus. The resistance to be measured is firmly connected to the two lower terminals marked BRIDGE TERMINALS, and the battery leads having been connected to the three low resistance Leclanché elements in the battery set, the plugs are inserted in the holes marked BRIDGE, thereby supplying current to the system. The key on the left



Connections for Testing Conductor Resistance.

completes the galvanometer circuit, and we proceed to obtain a balance in the usual manner. The following simple rules issued by the manufacturers for the preliminary setting of the proportional arms where the value of the resistance under test is approximately known, will be found useful:—

"For resistances between 1 ohm and 10 ohms, left-hand coil 100 ohms; right-hand coil 10 ohms.

"For resistances between 10 ohms and 100 ohms, left-hand coil 100 ohms, right-hand coil 100 ohms.

"For resistances between 100 ohms and 1,000 ohms, left-hand coil 100 ohms, right-hand coil 1,000 ohms."

The third figure can in all cases be obtained by interpellation, in the usual manner, employing the formula given under the heading of *Resistance Measurement by Wheatstone Bridge Method,* previously described in these paragraphs.

Infinity is obtained by withdrawing one or both of the dial plugs.

The following additional rules, issued by the manufacturers in respect of this test, should also be duly noted in using the apparatus:—

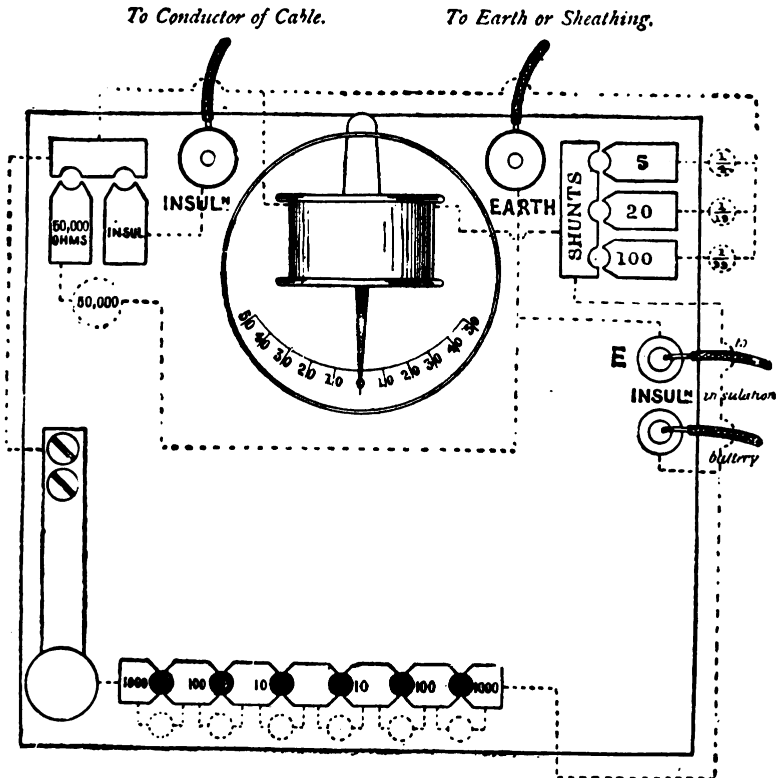
"Except in testing at the extreme range of the instrument, *i.e.*, quantities less than one ohm or greater than 1,000 ohms, the galvanometer will be found amply sensitive, and it is better to place the south end of the controlling magnet uppermost, thereby reducing the time of the oscillations of the galvanometer needle.

"The battery should be in circuit as short a time as possible to avoid running down the cells, and it is well to take out one of the battery lead plugs when any alterations are being made in the plug commutators, only replacing it just before pressing the galvanometer key.

"Care should be taken to connect the conductor to be tested very securely to the bridge terminals. This may be done for very large or stranded conductors, either by soldering to their ends thin brass plates with holes in them of a suitable size to go under the heads of the terminals, or the connection may be made by means of finer wires soldered to the end of the main conductor. The resistance of these must be independently ascertained, and subtracted from the gross result."

The insulation test is conducted in a slightly different

manner, and may be described as follows:—The insulation testing battery of 36 to 39 cells is connected by the flexible leads and concomitant plugs with the two holes marked INSULn., the cable under test and its earth or sheathing having been previously connected to the two upper terminals marked INSULn. and EARTH respectively. Referring now to the left-hand top plug switch, the plug is first inserted in the opening marked 50,000 OHMS in order to take the constant. This, with the available voltage of the accompanying set of cells, will be found to require the insertion of that shunt which



Connections for Testing Insulation Resistance.

gives a multiplying power of 20, which is equivalent to the deflection produced by the battery current through a standard resistance of one megohm. The true deflection thus obtained, or, in other words, the observed deflection multiplied by 20, gives us the insulation "constant," which term has been already explained. The plug is then withdrawn and re-inserted in the opening marked INSULn., when the deflection due to the cable, with or without a shunt, will be obtained. It remains, therefore, to divide the latter deflection into the former to ascertain the insulation resistance of the cable under test in megohms.

The key on the left may, if all the values in the proportional arms of the bridge be plugged up, be employed as a short circuit key across the terminals of the galvanometer, and, in this capacity, is useful for checking the oscillations of the needle.

By employing the maximum shunt, *i.e.*, the shunt giving a multiplying power of 100, a larger testing voltage than that described above may be employed with the same result, except that the constant will then be through an equivalent of five megohms instead of one, which fact must be taken into consideration in calculating results.

The following additional rules concerning this test are also excerpted from the manufacturers' instructions, and should be rigidly adhered to, if satisfactory results are to be obtained.

"(1) Too much care cannot be taken in preparing the ends of the cable. Since we are measuring a very small current of electricity passing from the conductor to the outside sheathing, through the insulated covering, it is clear that our results will be entirely misleading if any current be allowed to pass over a dirty surface at the ends where the conductor is exposed. These ends should be looked to before testing, and in the case of india-rubber or other firm material, the section of the insulator should be pared all over with a sharp and perfectly clean knife.

"(2) Care should be taken not to short-circuit the battery, which may easily occur in two ways. One is by allowing the two battery plugs to touch one another, when the other ends of the leads are attached to the

battery terminals; and another is by allowing the lead attached to the earth terminal to touch that attached to the insulation terminal.

"In both cases the battery of small cells will be for a time much overworked, and in the second the needle may become bent or demagnetised.

"(3) Another point that may be noticed is that in deducing the insulation resistance per statute mile from a test on any given length, the result obtained from a test on the latter is to be multiplied by the length of the piece in miles, and not divided by it."

Such a combination of instruments and apparatus as the one just described is admirably suited for installation work such as falls under the duties of mains inspector, wiring contractor, etc., etc., and, in fact, in all cases where a convenient portable testing set is required and

Norman Testing Switch for Insulation and Capacity Tests on Electric Cables and Circuits.

extreme accuracy is not essential, but, as its range is somewhat limited, it is unsuited for making tests on cables at the factory or in cases where comparatively high insulation resistances, often amounting to some thousands of megohms, have to be dealt with.

A switch and shunt combination which has been designed to meet the requirements of such cases, as also with a view to portability and general convenience, is that known as the Norman Testing Switch, designed by Mr. H. D. Norman, which by successive movements of a single lever serves to make and break the various circuits necessary in testing a cable or circuit for electrostatic capacity, insulation resistance, and consequent earth readings, together with the introduction of the necessary shunts, all of which are included upon the same base.

A general view of the switch is shown in the accompanying block, to which is appended a general plan dia-

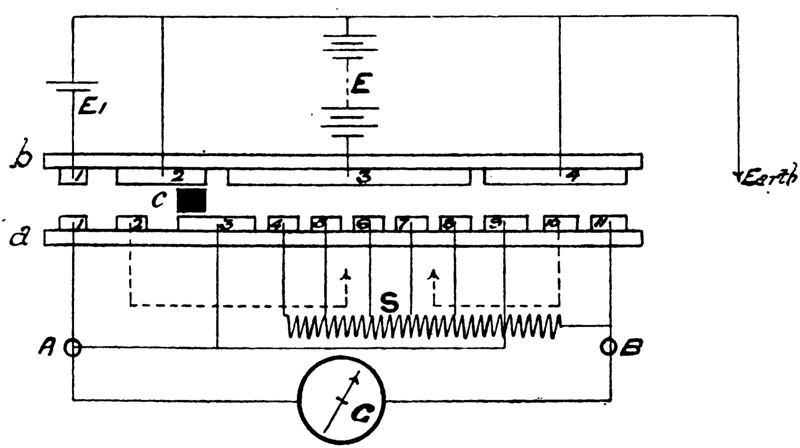


Fig. 68.

gram of connections, Fig. 68, showing the mode of connecting extraneous apparatus to the switch. Referring

to the latter diagram, *a* and *b* are two fan-shaped sheets of ebonite forming the vertical sides of the switch, and around the inner circumference of which are fixed a series of metallic contacts, *a*1, *a*2, *a*3, *a*4, — *a*11, *b*1, *b*2, *b*3, and *b*4. The (*a*) contacts are severally connected with the (*b*) contacts by the successive movements of the lever *c*, the sole office of which is to thus form a path of negligible resistance between these points; in other words, the lever forms a circuit key severally connecting them.

Of the external connections, A and B are the galvanometer terminals seen to the front of the complete illustration, of which A also provides a means for connecting the standard high resistance for insulation testing, the standard condenser for capacity measurement, and subsequently the extremity of the cable itself under test, respectively. G is the galvanometer, and S a set of shunts, wound with platinoid wire, and contained in the cylindrical ebonite covers seen in the front of the complete switch above. These shunts are arranged on the "Universal" principle, the various points of contact being connected to the studs *a*4, *a*5, *a*6, and *a*7, yielding 1-10,000th, 1-1,000th, 1-100th, and 1-10th shunts respectively, and, being constructed on the above principle, the switch is available for use with any galvanometer, without altering the respective multiplying powers of these shunts. E and E1 are the batteries for insulation and capacity measurement respectively, whilst the earth connections are arranged as shown. A subsidiary short-circuiting device upon the switch lever, with corresponding galvanometer contacts upon the inner surface of the front of the switch, serves to short-circuit the galvanometer during the initial charging period in insulation testing, the short circuit being removed as the lever moves forward over successive shunts, thus allowing the electrification readings to be taken.

Taking the various *a* and *b* contacts in turn, we will proceed to discover what happens when the connecting lever is moved over the range of the switch. Firstly, when connecting *a*1 and *b*1, the terminal A, and in consequence the cable or condenser connected between it and earth, is charged electrostatically from the battery E1; on moving the lever so that it connects *a*2 and *b*2, nothing happens unless a shunt be required in taking the

capacity throw, in which case the shunt required is brought into circuit by two small ebonite-handled plugs connected by a short length of flexible wire, one of which is inserted in the hole on the exterior face of the switch, corresponding to the shunt required, and the other in the hole corresponding to contact *a*2, thus completing the circuit indicated by the dotted line in the diagram of connections.

If no shunt be required in taking the capacity throw, the lever is moved so as to connect *a*3 and *b*2, thus discharging the cable or condenser. When the lever is next moved to connect *a*3 and *b*3, one pole of the insulation testing battery E is connected to A, and consequently to the cable if connected, the opposite pole being earthed; simultaneously the galvanometer is short-circuited by the device before alluded to, and so protected from injury due to the rush of current, on moving further to positions *a*4, *a*5, *a*6, and *a*7, connecting them respectively with *b*3, the 1-10,000th, 1-1,000th, 1-100th, and 1-10th shunts are successively brought into circuit, and the short circuit is at the same time removed from the galvanometer terminals. The connection of *a*8 and *b*3 gives the position of "no shunt;" then, the electrification readings having been duly noted, the lever is next moved to connect *a*9 and *b*4, when the cable will commence to discharge itself. Then, the initial rush of the discharge current being over, the lever may be moved to connect *a*10 and *b*4, when the necessary shunts for taking the "earth readings" may be introduced as in the case previously mentioned, when describing the capacity test with this apparatus, by inserting one of the plugs in the hole corresponding to the shunt required, and the other in that of *a*10. Finally, with *a*11 and *b*4 connected, the cable discharges itself in the "no shunt" position.

The capacity battery E1 is connected to the switch contact through a small plug switch at the back, so that it can be disconnected, if desired, by simply withdrawing the plug.

In brief, the mode of using this switch for capacity and insulation testing is as follows:—The testing batteries, galvanometer, and earth connections having been made as shown in the figure, the switch lever is moved over to the "no shunt" insulation position, and the leakage deflection, if any, noted; if used under ordinary

dry atmospheric conditions, there should be no leakage deflection with the testing voltage usually employed. The lever is then brought back to the position marked "Discharge" at the left of the front plate, and one side of a standard condenser is connected to terminal A, the other side being earthed.

The short circuit plug being removed from the condenser, the lever is brought to position 1, connecting $a1$ and $b1$, and thus charging the condenser. The charging should last for a definite period, such as 30 seconds, and, no shunt being as a rule required in taking the standard capacity throw, the lever is next brought to $a3$ and $b2$, and the deflection noted.

The next step consists in taking the insulation constant, and, to this end the standard condenser is replaced by one terminal of a standard high resistance, such as one megohm, for example, the remaining terminal being earthed as before. The lever is then moved over the shunt studs, $a4$, $a5$, $a6$, and $a7$, until a suitable deflection (the largest possible) is obtained and noted, together with the multiplying power of the shunt used. These two quantities, viz., the deflection and the multiplying power of the shunt, multiplied together and by the value of the standard resistance in megohms, which, in the case cited above, will be unity, constitute the insulation constant into which are divided the respective deflections obtained for the various cables, giving the insulation resistance thereof in megohms.

The constant having been duly ascertained in this manner, the standard resistance is disconnected from A and replaced by the extremity of the cable under test, the opposite extremity being free. The same operations are then repeated to obtain the respective deflections due to the capacity and insulation resistance of the cable, the latter being taken, as usual, at the end of one minute from the time of charging the cable. If earth readings are required, the extended movements of the lever over contacts $a9$, $a10$, and $a11$ are made as before described, and the ensuing discharge deflections duly noted, having regard to a similar time interval.

This switch forms a compact and useful combination for both stationary and portative purposes, dispensing

with shunt boxes, short circuit, battery, and condenser keys, all of which are included in its design.

The lever is provided with an insulating ebonite shield, as shown in the figure, which prevents the hand from inadvertently touching the upper contacts, and so receiving an unpleasant shock. The whole structure is well insulated on a corrugated ebonite base piece, and in a special design for outside work has been provided with a weather-proof cover, the lever movements being effected by means of an external handle at the centre of the switch front, which is attached to the axis of what is normally the lever handle.

We will pass on now to a consideration of various methods for the

Localisation of Faults on electric circuits, the preliminary treatment of which has already been dealt with in the preceding paragraphs under the heading of *Continuity or Circuit Test.*

Most of the tests for fault localisation which are to be dealt with in the following paragraphs are the outcome of the requirements of the electrician who has to deal with submarine cables, in that they refer more especially to long cable circuits of which both ends are not available at the testing point, but, nevertheless, there are several methods amongst those to be described, such as the "Loop" tests, for example, which are equally applicable to short lengths of cable or local circuits.

The simplest fault to localise is that due to a *complete break* in a cable or circuit, and consists of a simple resistance measurement. Thus, the original ohmic resistance of the circuit being known, if we measure the resistance between one extremity and the fault, as represented by earth if the cable be submerged, it only remains to divide the resistance thus obtained by the known resistance of unit length of the circuit, to determine the distance of the break from the available extremity in terms of that unit length.

For example, let us suppose that the original resistance of a uniform circuit 100 ft. in length was 20 ohms, then the resistance of one foot will be .2 ohm. If now, on measuring the resistance between one extremity and earth, we obtain a value of 5 ohms, we know that the distance of the break from that extremity will be

$5 \div .2$, or 25 ft. This method is, of course, only applicable in cases where the fault itself is making good earth, the resistance of which is negligible. As such is seldom the case, we must proceed to deal with those examples in which the earth due to the fault is not perfect, but offers an appreciable resistance to the passage of the current. These are known as

Partial Earth Faults. The various methods for the localisation of such faults are comparatively simple in principle of application, but are rendered somewhat more difficult in practice, especially in the case of submerged circuits, owing to the existence of earth currents, variation in fault resistance owing to chemical and electrolytic action, etc., etc.

We will deal with them in turn, commencing with

Blavier's Method.

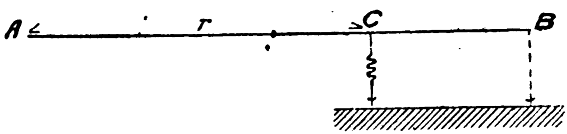


FIG. 69.

Let A B, Fig. 69, be a uniform circuit of which the total resistance R is known, and on which a partial earth fault exists at the point C. The extremity B is first insulated, and a resistance measurement taken between A and earth, the result of which gives us the resistance r of A C *plus* the resistance of the fault, which total we will call $r1$. The point B is then earthed, and a second resistance measurement made from the point A, earth being, as before, used as the return, which gives a result $r2$. Then $r = r2 - \sqrt{(r1 - r2)(R - r2)}$.

Kingsford's Method, which is a modification of Blavier's, ensures the passage of an equal current through the fault in the second case to that which flows through it in the first instance, when the extremity B is insulated. This fact is ensured by the introduction of a resistance R1 into the circuit, it being connected to that end of the cable which is nearer to the fault C.

Then $r = r2 - \sqrt{(r1 - r2 - R1)(R - r2)}$.

The mode of procedure consists in making R1 any value at random, and then obtaining rough values for $r1$ and $r2$. The value of r resulting from this rough test is then obtained from the above equation, and substituted in the following; $R1 = \frac{r(r1 - r)}{R}$, which, worked out, will give an approximate value for R1. The value thus obtained is reproduced upon the actual resistance, and the test repeated several times until the value obtained for R from the above equation is sufficiently approximate to the actual dimensions of R1 in the test to ensure a fair degree of accuracy in the results. When this point is reached, approximately the same current flows through the fault in both cases.

The *Overlap Method* is somewhat similar to the foregoing tests, but involves separate measurements from either extremity, A B, Fig. 69, of the cable. The respective extremities A and B are insulated in turn, whilst the tests are being conducted; thus B insulates whilst A is testing, and *vice versâ*. R, $r1$, and $r2$ standing for the same quantities as before, $r = \frac{R + r1 - r2}{2}$

Fahie's Method has for its object the elimination of polarisation and variation in the resistance of the fault caused by the corrosive action of the sea water in which it is immersed. It involves the employment of two galvanometers consisting of a simple astatic system provided with an index finger suspended by a silk fibre over a horizontal graduated dial, and protected from external disturbing influences such as would be produced by currents of air, by a glass shade. An ordinary reflecting galvanometer is too sensitive for this test. G and G1, Fig. 70, represent the two galvanometers connected as shown, whilst A, B, and C are the proportional and adjustable arms respectively of an ordinary P. O. bridge. K is a key of the familiar Morse type, the lever of which is connected to the line under test, and the remaining two contacts to the bridge and G1, as shown in the figure. E is the testing battery of from 50 to 60 cells.

The *modus operandi* is as follows:—The approximate resistance of the line is first ascertained in the usual manner, K being in contact with the bridge, and the

value obtained is left unplugged in C. K is then depressed so as to disconnect the line from the bridge circuit, and connect it instead to earth through G1. The

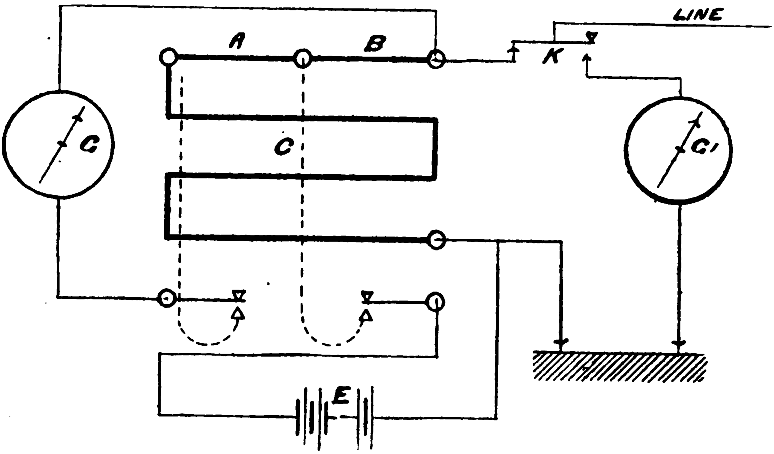


Fig. 70.

resultant deflection is a measure of the cable or polarisation current due to the fault, and we must proceed to neutralise it in the following manner:—The infinity plug being withdrawn from the bridge, all values in B are plugged up, and a current of *opposite polarity* to the cable current sent into the line by depressing the battery key, K being on the bridge contact. This current is kept on until a deflection in the opposite direction is obtained on G1, when K is again brought into contact with it, thus showing that the fault has been polarised in the opposite direction. When such is the case, K is kept in contact with G1 until the needle comes to zero, at which instant K is again put to bridge, and the infinity plug having been meanwhile replaced, the galvanometer key is closed, and the resultant displacement from zero noted. C is then readjusted, and the various operations repeated until a value is obtained for C at which, when the cable current is neutralised, the galvanometer key closed, and the bridge circuits connected, the needle of

G oscillates slightly over zero before moving rapidly over the scale under the influence of the returning cable current.

In making this test care must be taken to apply the same pole of the battery to the bridge circuits as was employed to neutralise the cable current, and also to make the necessary observations on the bridge galvanometer G at the same instant that zero is noted upon G1, as, from that moment, the fault will commence to polarise again in the same direction as before, and must be subjected to the further neutralising pole of the testing battery before any more observations can be taken on G.

Lumsden's Method has a similar object in view to that embraced by the foregoing, viz., the preliminary neutralisation of the polarisation current due to the fault. It is performed as follows:—The fault is first cleaned by the application to the end of the line of a zinc current from some 60 to 100 cells, the opposite pole being earthed. This application is continued for a period of from 10 to 12 hours, according to the requirements of the case, the direction of the current being reversed from time to time for a brief interval. The line and instruments are then connected up, as shown in Fig. 71, and a rough measurement of the resistance is made and left unplugged in the variable arm C of the bridge. A positive current from a battery consisting of some three cells to every 100 ohms resistance is then applied for the space of a minute or so, the effect being to coat the conductor at the fault with chloride of copper. Both keys are then depressed, and the plugs manipulated in such a manner as to keep the needle of the galvanometer G (which must be of the same type as that employed in the preceding test) at zero. The needle will be continually but slowly varying, and must be maintained approximately at zero by regulating C, until, at a certain point, the needle will be rapidly deflected, thus indicating the fact that the pure copper of the conductor has been exposed at the fault. The value in C at this moment gives the true resistance, in the absence of polarisation currents. The operation should be repeated and an average of the results taken; it will, however, not be necessary to apply the negative current for so long a period in the second case, from 20 to 30 minutes

usually proving ample for the purpose. If the fault be near the extremity of the line attached to the bridge, the necessary time for the manipulation of C may be

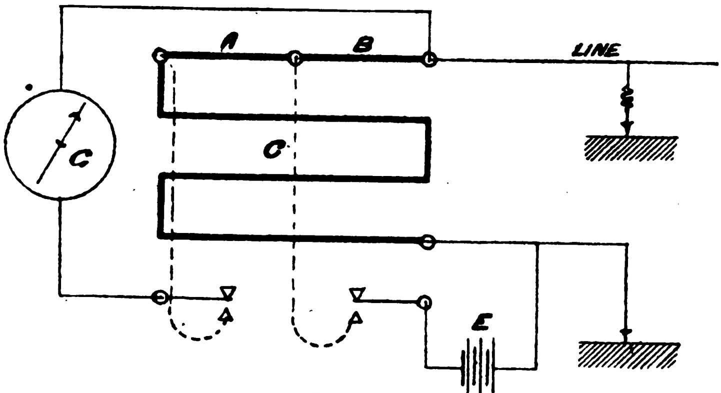


FIG. 71.

gained by the introduction of a known resistance between it and the bridge, thus lessening the current effect and increasing the time interval. The value to be given to this resistance must be determined experimentally, and it must, of course, be deducted from the ultimate results obtained in the test.

Mance's Method has for its main object the elimination of errors due to earth currents which are distinct from the polarisation currents set up at the fault, in that they are the result of a difference of potential existing between two points on the earth's surface occupied respectively by the available extremity of the cable and the fault.

The connections for the test are the same as indicated in Fig. 71, and the method consists in making the resistance measurement in the usual manner, first with two equal values *r* such as the 100 ohm coils in the proportional arms A B of the bridge, and secondly with two other equal values *r*1 such as the 1,000 ohm coils, for example. Let R and R1 be the respective values unplugged in the variable arm C of the bridge in either of

the above cases, and let Re be the resistance of the testing battery, then the required resistance

$$x = \frac{R\,(2\,Re + r) - R1\,(2\,Re + r1)}{(R1 + r1) - (R + r)}$$

The first measurement with the proportional coils r unplugged is continued until it becomes steady, and the galvanometer is then short-circuited for an instant or cut out of circuit by its key, whilst the proportional coils are changed to $r1$, when a fresh value in C, usually larger than R, will be obtained on balancing.

Jacob's Deflection Method dispenses with the necessity for using a Wheatstone bridge in the actual test made on the cable, the speedy manipulation of its plugs being somewhat inconvenient.

The instruments are first connected as indicated in Fig. 72, and consist of the testing battery E, a battery reversing switch S, and a Thomson reflecting galvanometer G, with a reversing key K, short-circuit key K1, and low resistance shunt s. The suspended system of the galvanometer G is turned so that it has a false zero at one extremity of its scale instead of in the centre, as is usually the case. The battery switch is first closed, and that side of the galvanometer key K depressed which tends to give a deflection over the range of the scale, the resulting deflection d being regulated as regards its convenient dimensions by the shunt s. The keys are then opened, and the battery current reversed by means of its switch, the other side of the galvanometer key K being depressed in order that the second deflection $d1$ may be in the same direction as the first. Owing to the earth current, these two deflections d and $d1$ will have different values, and the shunt s must be manipulated until they are both conveniently within the range of the scale. A series of measurements is then taken with either pole of the battery, the key K1 being employed to check the swing of the galvanometer, and so tend to rapid working. An average of d and $d1$ is obtained from the series, and the line and earth are then disconnected and replaced by a set of adjustable resistances. The same operations are then repeated, and the value of the resistances adjusted to r and $r1$, such that the deflections d and $d1$ are reproduced.

The deflections d and $d1$ are, of course, represented by the sum of the degrees on either side of the true zero.

Then the required resistance $x = \dfrac{dr + d1\,r1}{d + d1}$

If it be necessary to use what is known as an "in-

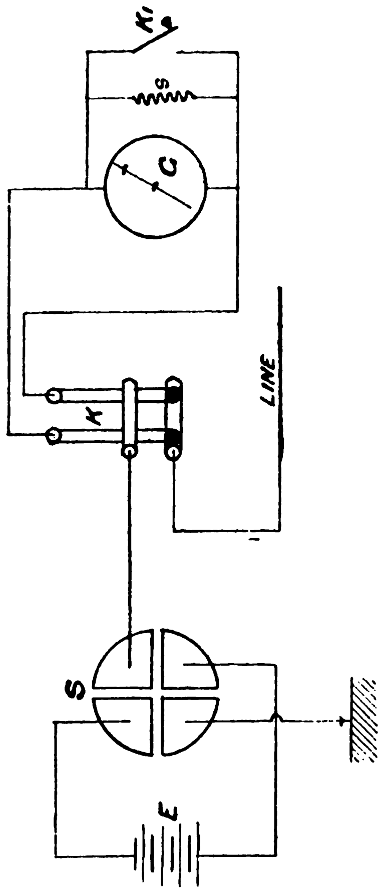


Fig. 72.

ferred zero" for this test, that is, if the suspended system of the galvanometer is set to such an extreme

that, normally, the spot is entirely off the scale, then we require to know R, which is the combined resistance of the battery E and the shunted galvanometer G, and

$$x = \frac{2(R + r)(R + r1) - R}{(R + r) + (R + r1)}$$

Kempe's Loss of Current Test is comparatively simple, but necessitates the use of two galvanometers, one at either end of the line A B, Fig. 73. The testing battery E is of low resistance, and is connected through the galvanometer G and compensating battery E1 to the line at the point A. E1 is a low resistance battery of one to two cells, to balance the earth current if such exist in the line, and the testing battery E should be connected in the same direction. *s* is a shunt across the terminals of E1 for its final regulation, so that it exactly balances the earth current. To effect this adjustment, E is first disconnected, and the corresponding terminal of G put to earth. *s* is then adjusted until no deflection is obtained, when E is again connected up, as shown.

G and G1 are Thomson reflecting galvanometers provided with low resistance shunts. Simultaneous observations are made on G and G1, which are then connected up under the same conditions with a standard cell and a resistance, which, in combination with the galvanometer resistance, will allow the passage of, say, one milliampère. The resulting deflections are noted and divided into the deflections previously obtained, when the galvanometers were connected to the cable. The quotients, which we will call C and C1, represent the respective currents which flowed through the galvanometers G and G1 when connected as in Fig. 73 above. Then the required resistance x between the extremity A and the fault, $x = \dfrac{Cr - C1\,(R + Rg)}{C - C1}$ where R is the original conductor resistance of the line between the points A and B, and Rg the resistance of G1. r is the resistance on the far side of the extremity A through earth, and can be ascertained by disconnecting the batteries E and E1 and galvanometer G from the line and earth, and connecting them instead through an adjustable resistance which is varied until the original deflection is reproduced, then its value is the same as r.

Clark's Fall of Potential Method is illustrated in Fig. 74, where B D is a length of cable having a fault at the point C. A B is a length of good cable of resistance

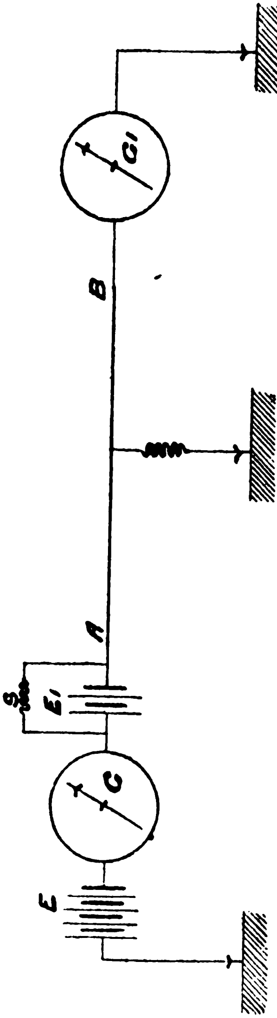


Fig. 73.

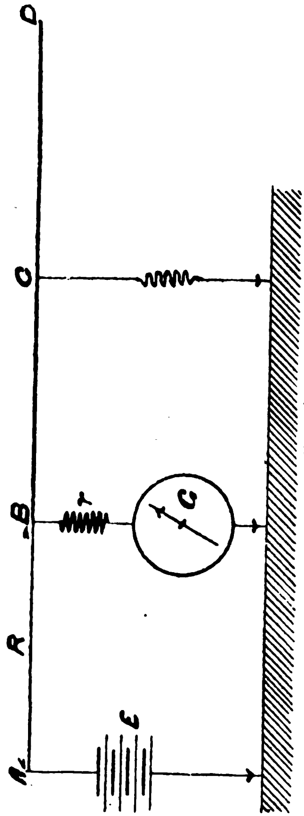


Fig. 74.

R, joined in series with it. E is a battery of constant E.M.F. connected between the point A and earth, and G is a galvanometer of the d'Arsonval type in series with a resistance r, such that their combined resistance is appreciably greater than that of the line under test. G is first connected between the points A and B, D being insulated, and the deflection due to the fall of potential from A to B noted; we will call it d. G is then disconnected, and connected instead as shown in the figure between the point B and earth, and the resulting deflection $d1$ is also noted. The galvanometer G is then removed, and set up under exactly the same conditions as to scale distance, etc., at the point D, and connected between the point D and earth, the third deflection $d2$ being noted, then the resistance between the point B and the fault, $x = \dfrac{\text{R}\, d1 - d2}{d}$

It is quite possible, with a D'Arsonval galvanometer, to shift it in this manner without altering its constant, but, if such an instrument be not available, or if the extremities B and D are so far apart that independent tests with various apparatus have to be taken, involving the use of two distinct galvanometers, then the test is rendered somewhat more complicated, as the instruments must afterwards be connected in series with a high resistance and standard cell, and their "constants" noted in terms of the E.M.F. of the standard cell, thus providing a means of comparing the respective deflections d, $d1$, and $d2$, on the same basis, and reducing them all to the values they would have attained had they all been produced upon the same instrument, as described above.

Siemens' Equal Potential Method is somewhat similar to the foregoing, and is illustrated in Fig. 75, where A B is a line having a fault at C. The mode of procedure is as follows:—The battery E, of constant E.M.F. is connected as shown between the extremity A and earth, the point B being insulated. A galvanometer (preferably D'Arsonval) is then connected between A and earth, and the deflection d noted. The galvanometer is next connected between B and earth, and a second deflection $d1$, due to the potential at B, and consequently at the point C, is obtained. The battery is then dis-

connected from A and connected instead between B and earth, the same pole being connected to the line as in the first instance; then, the galvanometer being con-

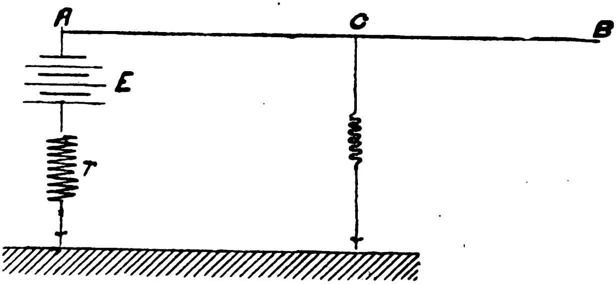


FIG. 75.

nected between the point A and earth, the resistance r in the battery circuit is adjusted until the second deflection $d1$ is reproduced. The galvanometer is then again connected between the point B and earth, and a third deflection $d2$ is obtained; then, taking L as the total length of the line A B, the distance x between A and the fault at C, $x = L \frac{d - d1}{(d2 - d1) + (d - d1)}$

Of course, if separate galvanometers, or a single instrument with a variable constant be employed in making this test, the same remarks as to the reduction of the values of d to a common comparative basis apply as in the preceding case.

Siemens' Equilibrium Method is illustrated in Fig. 76, and its principle consists in so arranging two independent electromotive forces, one at either end of the line, that the potential at the fault is zero, and no current in consequence will flow to earth at that point.

A B, Fig. 76, represents the line under test with a fault at the point C. E and E1 are two batteries with their opposite poles connected to the extremities of the line through the resistances r, $r1$, $r2$, and $r3$ respectively, of which $r1$ and $r2$ are equal fixed values, and r, $r3$ adjustable. Two galvanometers giving the same "con-

stant," or one instrument with a non-variable constant, such as a D'Arsonval, which can be moved from one extremity to another of the line, are then connected across the resistances $r1$ and $r2$ respectively or in turn, high resistances being placed in series with the instrument or instruments, in order, as before, to make the total resistance high as compared with that of the line. The

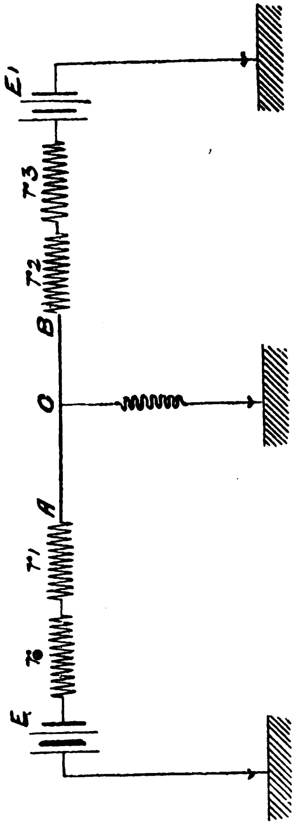


Fig. 76.

resistance r, or $r3$, is then varied until the same deflection is obtained in either case. The galvanometer is then disconnected from $r1$ and $r2$, and connected instead

between the junction of r and $r1$ and earth, and the point A and earth, thus obtaining two distinct deflections, d and $d1$ respectively, then $x = r1 \dfrac{d1}{d - d1}$

Of general fault localisation systems, however, those known as the "Loop" methods are by far the most satisfactory in that they are, within certain limits, independent of the resistance and E.M.F. set up at the fault itself. It is necessary, however, for the conduct of such tests that both extremities of the cable or line under test, or even two extremities of two separate cables or lines looped together at their far extremities, be available at the testing point for connection to the apparatus. Thus, if both ends of the faulty section of a certain cable be not available, it may be looped at its distant extremity with a return cable running parallel to it, or even with a totally independent cable, so long as two extremities of the complete loop are available for connection to the testing apparatus.

There are two distinct methods of loop testing, known respectively as Murray's and Varley's. We will deal in the first instance with

Murray's Loop Test.—The connections for this test with the ordinary P.O. pattern of Wheatstone bridge are shown in Fig. 77, where A, B, and C are the proportional and adjustable arms respectively of a P.O. bridge, D H. the loop of cable under test with a fault at the point F; E the testing battery of sufficient E.M.F. to send a current through the resistance of the fault, and G the galvanometer. The values in B are all plugged up so that the galvanometer connection can be made through the key, as shown, which key, under the usual conditions of usage, acts as the battery key. The *modus operandi* consists in unplugging a suitable value in A, which value is roughly determined by experiment, and then adjusting C until a balance is obtained on the galvanometer.

Then the distance of the fault from the extremity D, $x = L \dfrac{A}{A + C}$ where L is equal to the total length of the loop. The value thus obtained for x will be in terms of the same unit of length as L. If it be impossible to obtain a balance on the galvanometer G under

the conditions depicted above, there is either a mistake in the connections, which should be inspected in order to discover and correct it, or the fault may be very near the extremity D, in which case the ends of the loops should be reversed and the operations repeated.

Murray's test can also be conducted with the aid of

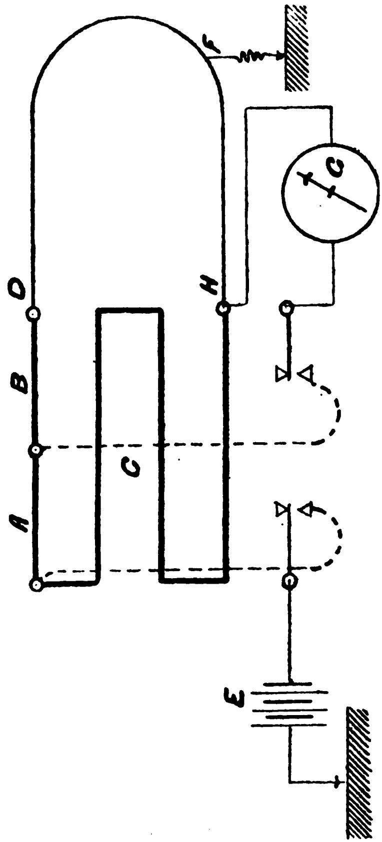


Fig. 77.

an ordinary slide wire or metre bridge, as indicated in the accompanying Fig. 78, which is a diagram of the connections in such case, the lettering being the same

as in the preceding figure. The slider S is moved along the wire until a point is reached at which a balance is

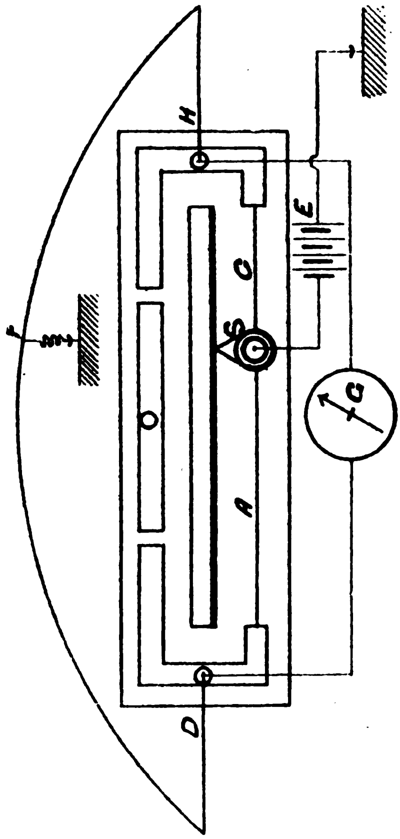


Fig. 78.

obtained on the galvanometer G; the same formula then applies, the values of A and C being reckoned in degrees on the attached metre scale, and, if the slide wire be homogeneous, as it should be, very satisfactory results are obtainable by this method.

A rough indication of the locality of a fault can be

obtained by this method in the following manner:—A short length (about one yard) of any suitable wire, such as No. 20 gauge, is sweated across the terminals of the loop D H, and treated as the slide wire in Fig. 78, the battery connection being slid along the wire until a balance is obtained. The respective values corresponding to A and C in the preceding test with the *bonâ fide* metre bridge are then obtained by direct measurement, and inserted in the formula, as before.

I must here digress for a moment to consider the subject of contact and other influences upon this and similar loop tests. To begin with, the extremities of the loop should be directly connected to the bridge terminals if possible, but, if leads be interposed, their equivalent lengths must be determined and allowed for in calculating results.

Thus, if the cable forming the loop be 7-16, and say one yard of No. 16 gauge wire be interposed between the extremity D and the bridge terminal, that connecting lead will be equivalent to 7 yards of the actual loop, and such an allowance must be made in working out the results.

As regards the connections, if cables of very large sectional area are involved, it is better to employ mercury cups to connect them with the apparatus, the ends being previously well cleaned and amalgamated.

If the ordinary bridge be used in Murray's test, it is very probable that the resistance in A will be greater than the resistance of the loop connected to it, and, in this case, the galvanometer lead must be attached to the extremity of the loop itself on the *cable* side of the bridge connection, so as to include any possible contact resistance in the bridge circuit. If, on the other hand, the slide wire bridge be employed in the test, the reverse will probably be the case, and the galvanometer may be connected direct to the terminals of the slide wire for a similar reason. In pursuance of the above precaution it is better in using the P.O. bridge to connect the galvanometer directly across the loop at the points D and H, and employ a separate key in circuit with it rather than run the risk of contact error by using the right-hand key of the bridge, as indicated in Fig. 77.

Varley's Loop Test is somewhat similar to Murray's,

but necessitates the use of a Wheatstone bridge, the ordinary metre bridge being unsuitable. The connections are indicated in Fig. 79, and are similar to those for the

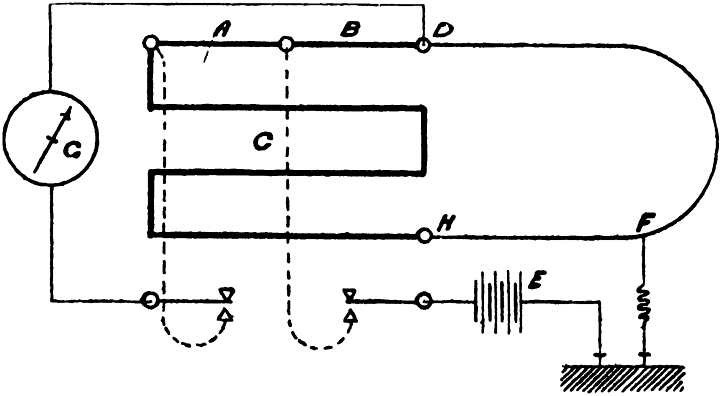


Fig. 79.

measurement of resistance by the bridge method, with the single exception of the battery connections, the positive pole of the latter being connected to earth instead of to the bridge, as usual. The lettering in the figure is the same as in the preceding case.

The proportional values usually unplugged in A and B for this test are 1,000 ohms and 10 ohms respectively; then, the battery key being depressed, C is adjusted until a balance is obtained on the galvanometer G. This value for C having been obtained and noted, the positive pole of the battery is now disconnected from earth and connected instead to the same terminal as the extremity H of the loop, thus completing the ordinary connections for resistance measurement by the bridge method, and a fresh balance is obtained, giving a value R as the conductor resistance of the loop D H. Then, taking L as the length of the loop, the distance of the fault F from the extremity H can be obtained from the formula

$$x = L\,\frac{(A\,R\ -\ B\,C)}{R\,(A\ +\ B)}$$

To ensure accuracy, the ends of the loop may then be

reversed, and the connections being again made as represented in Fig. 79, a fresh balance is obtained, and the distance from the opposite extremity of the loop computed therefrom. The sum of these two distances should, of course, be equal to L, the total length of the loop; if, however, their values vary slightly, the mean of the two may be taken as correct; if a large variation results, the connections and contacts should be examined for possible errors.

Of course, if leads be used between the bridge and the extremities of the loop, their equivalent lengths must be determined and allowed for in calculating results, as mentioned in connection with the preceding test.

Reverting for a moment to Murray's test, better results are frequently obtained by reversing the positions of battery and galvanometer, but this must not be carried into effect if there be any possibility of a polarisation E.M.F. set up at the fault itself, for, in such case, on closing the galvanometer key alone, a deflection would ensue owing to this E.M.F., and the ultimate adjustments would be made to a variable false zero, and, in consequence, no satisfactory balance would be obtained on the galvanometer. In cases where the absence of such an E.M.F. is assured, however, it is often possible to obtain more satisfactory results by reversing the positions of battery and galvanometer in this test, as, in such case, the current has not to overcome the resistance due to the fault itself in its passage, but is provided with a free path of comparatively low resistance, the fault resistance being inserted in the galvanometer circuit instead.

Varley's method is unsuitable in cases where the loop is of comparatively low resistance owing to the difficulty of measuring the latter on the ordinary Wheatstone bridge. It is, however, often used when suitable, owing to the similarity of the connections to those for resistance measurement, which will often be arranged as permanencies where a considerable amount of conductor resistance measurement has to be dealt with; Varley's test involves a very slight modification of these connections, and is often adopted for this reason.

It sometimes happens that a conductor is broken without actually severing or damaging the surrounding insu-

lation. More especially is this the case with single wires of small gauge insulated with india-rubber. Such breaks are very easily located by treating the two severed portions as separate condensers, charging each of them in turn for a definite period with a battery of sufficient E.M.F. to give a suitable discharge deflection, and then noting the discharge deflection, which we will call d and $d1$ respectively. Let L be the total length of the circuit, and l the length of that portion giving, say, the deflection d, then the distance of the break from that extremity which was connected to the galvanometer when d was obtained is given by the formula, $l = \frac{Ld}{d + d1}$

The connections for the test will be the same as those employed in the measurement of electrostatic capacity by the direct deflection method, the two extremities of the broken circuit taking the place of the standard and condenser under test respectively, and a good earth is necessary for satisfactory working.

Most of the foregoing methods for the localisation of faults on electric circuits apply more especially to those cases where the cable or line has been laid or fixed in position. If, on the other hand, the cable be wound on a drum or bobbin at the factory, and a fault have developed, say, in process of manufacture, several very efficient methods are available for localisation by running the cable over from one drum to another or into a tank of water, and the fault may thus be found and repaired on the spot, where everything required for the purpose is at hand, thus simplifying the matter considerably.

We will proceed to deal with these methods in turn by considering the manner of their conduct in practice.

A very simple method of localising faults of appreciable magnitude in a length of core when available for manipulation in the manner described above, is represented in Fig. 80.

The coil of wire under test is wound over from the drum D on to the drum D1 through water in an insulated trough T. One extremity of the wire is connected by a suitable well-insulated commutator and brush on the spindle of drum D with one pole of a battery E, the remaining pole of which is connected through the gal-

vanometer G with the water in the trough T. When the fault passes into the water in the trough, it affords a direct path for the current from E, and a deflection is, in consequence, produced on G. It is necessary for this test that the outer surface of the core under test

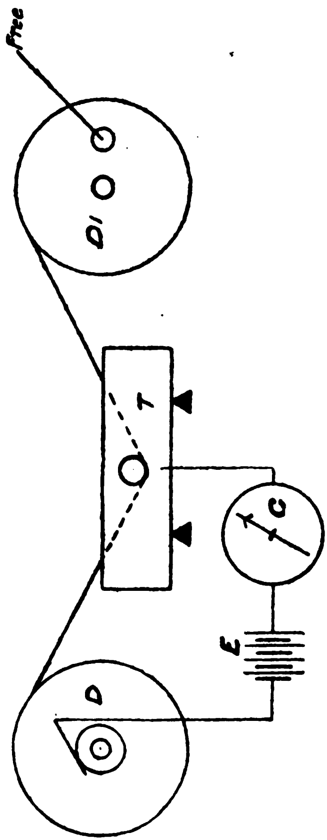


Fig. 80.

should be primarily dry, as otherwise the leakage through the fault and over the surface of the wet tape or other external covering will give rise to a permanent deflection

on the galvanometer, and so disturb the definition of the test.

Warren's Method, as performed with a sensitive galvanometer, is indicated in Fig. 81, where D and D1, as before, indicate the two drums, which should be of metal, or metal sheathed, in order to provide a ready path for the leakage current from the wet surface of the coil.

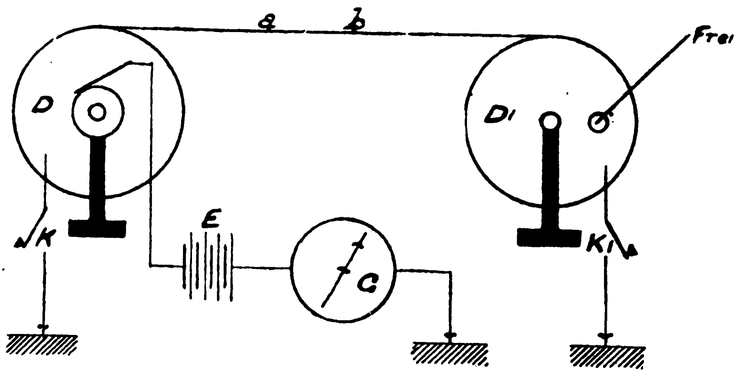


Fig. 81.

The core is wound on the two drums, as indicated, and a portion, *a b*, some 6 ins. in length, between the two drums, is cleaned and dried. The metal or sheathing of each drum is then put to earth in turn, by means of the keys K and K1, and the respective deflections, with due allowance for electrification, and the length of core on each drum, are noted; the larger deflection indicates, as a rule, the drum on which the fault lies, it being that drum which was earthed at the time. The core is then wound off that drum for a certain distance and the test repeated, until the fault lies between the drums. The whole portion from D to D1 is then cleaned, and an earth wire passed slowly along (a moist rag or sponge connected to earth answers very well), until the deflection is again obtained, thus indicating the exact location of the fault. Needless to state, the drums D and D1 require to be well insulated in the first instance, a very good plan being to mount them on wooden platforms provided with four feet in the shape of porcelain telegraph insulators, in-

verted, and secured to the platform, or, better still, special oil insulators may be used, and form a very effective mode of insulation.

Jacob's Method is illustrated in Fig. 82, where D and D1 represent two metal sheathed drums, one of which, D, is directly connected to earth, and the other, D1, is

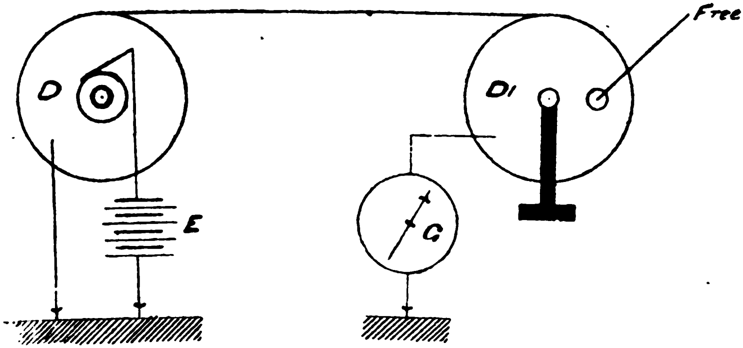


FIG. 82.

insulated in itself, but connected to earth through the galvanometer G. E is the battery, one pole of which is connected to the extremity of the conductor as shown, and the other to earth. The core is wound over from

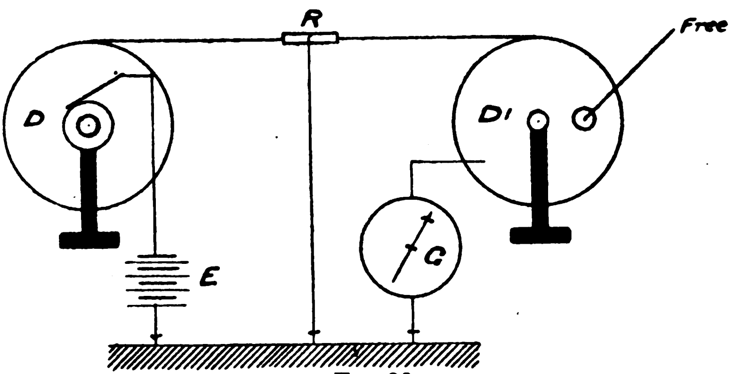


FIG. 83.

D to D1, and, while the fault is on D, all the leakage current from it passes to earth *viâ* the sheathing of D, but, as soon as it arrives on D1, the leakage current, or at least part of it, passes through the galvanometer G, and a deflection results. The exact position of the fault can, as in the previous case, be located by passing the galvanometer connection, in the form of a moist rag, over the surface of the core in the immediate vicinity of the fault, it being arranged between the drums for that purpose.

A similar method is depicted in Fig. 83, where D and D1 represent two insulated drums as before, E the battery connected between the conductor under test and earth, and G the galvanometer connected between the drum D1 and earth. R is a moist rag or sponge connected directly to earth. The core is wound over from D to D1, all leakage from the fault on D going to earth *viâ* R, until the fault passes over, when part of the current passes to earth through G, producing a deflection; the winding is then stopped, and the fault located by sliding R slowly along the surface of the insulation.

Another method is illustrated in Fig. 84, and consists, as usual, in winding the core on the two metal or sheathed drums D and D1, both of which are insulated and connected with a switch S, by means of which they can be put to earth, either independently or in conjunction with one another, as required. T is a tank of water through which the core is passed, its position during working being maintained by passing it under a smooth grooved pulley (a shackle insulator answers the purpose admirably) at the centre of the tank. The galvanometer G and the battery E are connected between the tank and the extremity of the conductor. The mode of procedure is as follows: D and D1 are earthed independently in turn, and the resulting deflection from one or the other is an indication of the drum on which the fault lies. Thus, if D1 be earthed, and a deflection results, it is caused by a leakage current from the fault on D, which, travelling by way of the moist surface of the tape or other external coating, returns to the battery *viâ* the tank and galvanometer, its only course, since D is insulated, and *vice versâ*. The choice of drums having been made in this manner, both D and D1 are earthed,

and, the battery and galvanometer being still connected as shown, the core is wound off that drum on which the fault lies until a deflection is obtained on G. This indicates that the fault has just left the drum, and, by cleaning and drying a portion, it can be more exactly located by drawing it slowly through the water until the deflection again occurs. Having been thus located and wound on to the opposite drum, its effects disappear as the leakage current goes to earth, and any further faults

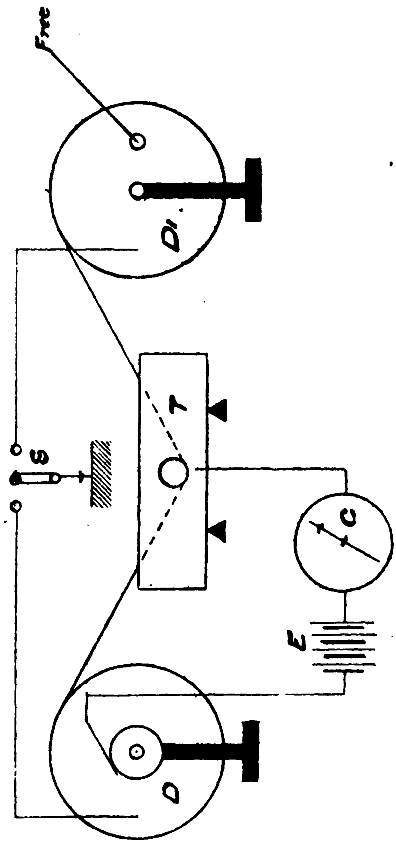


Fig. 84.

behind can be localised in like manner without removing the coil for repairs.

It will be noted in the diagrams illustrating the foregoing methods of fault localisation between drum and drum, that the opposite extremity of the conductor to that connected to the remainder of the apparatus is marked "Free." This means free, not only in the ordinary acceptation of the term, but also electrically free from surface leakage—*i.e.*, the surface of the insulation to the extent of three or four inches from the point where the conductor is bared must be cleaned, dried, and, if need be, waxed, in order to eliminate any possibility of surface leakage, which latter, if it exist, tends to give rise to secondary deflections which may be regarded as due to the proximity of the fault, and, in this manner, destroy the thoroughness of the test.

For a similar reason the insulation of the drums and tanks, where indicated, should be as perfect as possible.

As regards the battery power to be employed in these tests, there is no hard-and-fast rule, as it depends upon circumstances, such as the resistance of the fault, resistance to leakage current of the surface of the insulation, degree of dampness of the latter, etc., etc., but, as a rule, a voltage almost, if not quite as high as that employed for the measurement of insulation resistance will be required. If a primary battery such as the Leclanché type be used for the purpose, the cells may be protected from short circuit consequent on the passage of dead earth faults by the insertion of a high resistance, such as 10,000 ohms, in series with the battery.

The galvanometer used should be fairly sensitive; a Thomson reflecting instrument, duly provided with a shunt box and short circuit key, answers very well, and an instrument of the D'Arsonval type even better in that its movements are dead beat, and unaffected by the movements of the drums, etc., if of iron, in its vicinity.

To pass on to the subject of fault localisation by the application of a more or less powerful generator current. This is a practice sometimes resorted to in cases of emergency, and usually consists in the actual burning out of the fault by the application of a current of sufficient magnitude for a short period. Thus, an earth or partial earth fault on an electric light or power circuit may

often be localised in cases of emergency by passing a current from any convenient generator, such, for instance, as one of the dynamos supplying that particular circuit, through the fault, one pole of the machine being connected to the faulty circuit and the other to the metallic sheathing or armouring of the cable if it be of that description, or, failing this, to an effective earth in the immediate neighbourhood, which, needless to state, *should not take the form of a gas pipe.* A suitable fuse should be inserted to protect the machine, and prevent undue rush of current on the actual breaking down of the fault, and, above all, the test should not be applied except in cases of emergency, where time is an object, and, even then, only when the faulty section is under the more or less immediate surveillance of a responsible individual competent to check at once any undue combustion of insulation, woodwork, or other inflammable material in the immediate neighbourhood of the fault. The drawbacks to this crude system of fault localisation are several in number, chief amongst which may be mentioned (1) the actual destruction, by the heating effects of the current, of most evidence as to the cause of the fault; (2) the destructive effect of the current upon the immediate surroundings of the cable; and (3) the risk of fire consequent upon the test. The only merit of such a system is its time-saving quality, in that it affords immediate visual evidence of the locality of a fault.

Short-circuits, due to temporary accidental contacts between two cables, may often be localised by this method, the second cable being connected in place of the earth, whilst faults in concentric cables between the inner and outer conductors, or between the outer conductor and earth, may be found in like manner. In the former case, if a partial contact exist between the two conductors, it may often be located by passing a steady current of some ten to twenty ampères, regulated by a suitable resistance, through the fault, the said current being maintained for a definite period, will cause an appreciable rise in the temperature of the cable at the fault owing to the imperfect contact at that point, and this rise will ultimately extend through the whole substance of the cable for a short distance on either side of the fault, which may then be located by passing the hand lightly

along the exterior of the cable in the expected vicinity of the fault, when the warmth of the cable at that point will afford sufficient evidence of its immediate locality.

A total or partial disconnection in an insulated cable or wire, where the broken extremities are maintained in imperfect contact by the surrounding insulation, may be localised in like manner by connecting the two extremities of the faulty section through a suitable resistance or cut-out to a generator, when the arc set up at the fault, or heating due to the high resistance offered to the passage of the current at that point, will give sensible evidence of the position of the disconnection.

In all cases cited above, if the resistance of the fault be sufficiently great to oppose the passage of an ordinary low tension current, a higher voltage, varying from one to five thousand volts, according to circumstances, will frequently overcome this obstacle, and similarly assist in the localisation.

I wish it to be distinctly understood that in mentioning the above instances for emergency fault localisation in electric circuits, I do not recommend their general adoption, but have rather included them in this series to illustrate what can be done, and what to a limited extent is done, especially in American and Continental practice, in order to get over the difficulty caused by a temporary breakdown in mains and circuits. In all the cases referred to in the foregoing paragraphs thoroughly reliable safety precautions should be adopted; the tests should only be applied to circuits which are available for immediate inspection; and, above all, they should be carried out under the immediate supervision of experienced men.

The fault or faults having been duly located and repaired, the next proceeding is obviously to test them (the repairs or "joints," as they are commonly termed) in order to ascertain if they have been satisfactorily carried out, and this we will now proceed to discuss under the heading of *Joint Testing*.

Clark's Accumulation Method is illustrated in Fig. 85, the apparatus required for its conduct being a well-insulated trough T, the insulation of which may be effected by suspending it from a convenient support through the medium of ebonite rods; a sensitive high resistance gal-

vanometer G, a testing battery E, capable of yielding from 200 to 300 volts *at least*, a condenser C, and a Webb's discharge key K. The perfect insulation of the trough must be first ascertained, and, to this end, the pole of the battery which, in the figure, is connected to the extremity of the core containing the joint, is connected to the plate P which is immersed in the water in the trough, and the key K is depressed, thus charging the condenser C. The battery is then disconnected, and,

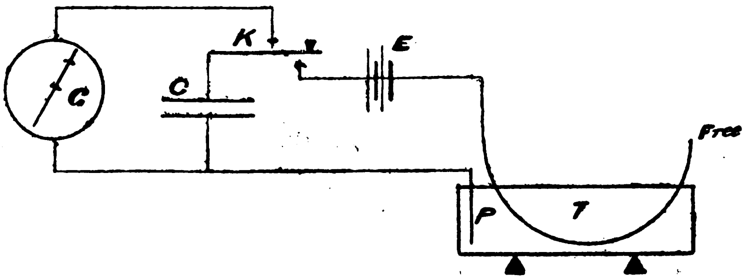


FIG. 85.

after an interval of, say, one minute, K is released, and the discharge deflection noted; it should be practically equivalent to the deflection obtained when C is instantaneously discharged at the completion of the charging period.

The insulation of T being thus assured, the joint is immersed, care being taken to clean and dry the insulation on either side for the space of a few inches to prevent surface leakage, and connected with the remainder of the apparatus as indicated in Fig. 85. All being in readiness, the short circuit plug of the condenser C is inserted, and the key K depressed; still keeping K down, the short circuit plug is withdrawn, and the condenser immediately receives a charge from E through the joint. At the end of a stated period of, say, one minute, the key K is released and the discharge deflection noted. This should amount only to one or two degrees, and is compared with that obtained when a perfect piece of core is substituted for that containing the joint. The deflection obtained from the former should not be greater

than that resulting from the latter; if it be so, the joint is defective.

The Discharge Method is primarily the opposite of the foregoing, and consists in fully charging the condenser, which is then allowed to discharge itself for a stated period through the joint, its subsequent discharge deflection at the end of that period being duly ascertained and compared with the instantaneous discharge; if the joint be good, there should be very little difference between the two deflections.

Raymond-Barker's Accumulation Null Method of Joint Testing.—Referring to the two joint tests described a few paragraphs back, it will be seen that they consist in comparing the leakage of current through the dielectric of the joint, either into or out of a condenser, and, as this leakage in the case of a perfect joint must of necessity be extremely small, it follows that any extraneous leakage, however slight, such as that caused by the imperfect insulation of the trough T, Fig. 85, will exercise an appreciable effect upon the test, especially under varying atmospheric conditions, *i.e.*, when the reading from the joint proper may be taken under different conditions to that from the comparative sample of perfect core.

It follows, therefore, that a test which allows of simultaneous observations on both joint and core, is much less liable to error than one in which the observations are made separately, and the following method provides a means of attaining the required result. It is represented in Fig. 86, where T is a well-insulated ebonite trough divided into two portions, also well insulated from one another by a central partition. *p*, *p*1 are contact plates immersed in water in the troughs which contain the joint under test, and the comparative length of perfect core respectively C and C1 are two equal condensers, E a battery of high E.M.F., and G a reflecting galvanometer. K1, K2, and K3, shown respectively as two Webb's discharge keys, and a simple circuit key, are combined in Price's mixing key, whilst K4 is a second simple circuit key. The *modus operandi* is as follows:—K1 and K2 are depressed simultaneously (one movement of the combination key effects this), thus charging C and C1 with electricities of opposite sign through the joint and core

respectively. K1 and K2 are then released, and allow the charges to mix with a tendency to neutralisation. K3 and K4 are then closed, and any preponderance of one charge over the other produces a deflection on G, which will be to one side of the scale zero or the other, according to which possesses the higher insulation, the joint or the core. The direction of indication may readily be determined by experiment with two core samples of known inequality of insulation.

If, in the aforementioned joint tests, the core or joint form part of a circuit of appreciable magnitude, the short circuit plugs of C and C1 must, in the first instance, be inserted, and withdrawn after depressing K1 and K2.

Having thus far dealt with the ordinary routine of testing, we will now proceed to discuss certain matters which, although beyond the pale of testing pure and simple, are nevertheless connected with it, and in many cases have an important bearing thereon. The major portion of the following matter has been culled from recent publications, periodical and otherwise, and, this being the case, it will tend by its presence to bring the foregoing information up to date. We will deal with them severally under the convenient heading of

Miscellaneous.

Price's Guard Wire.—The merits of this device were

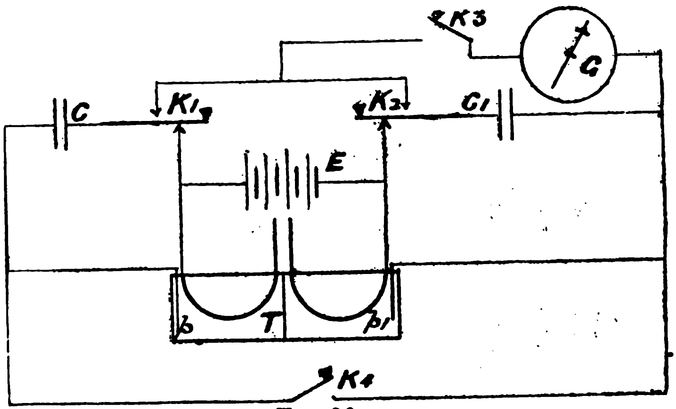


Fig. 86.

recently discussed in a paper read before the Institution of Electrical Engineers, and it merits special mention in that it is a successful application for the elimination

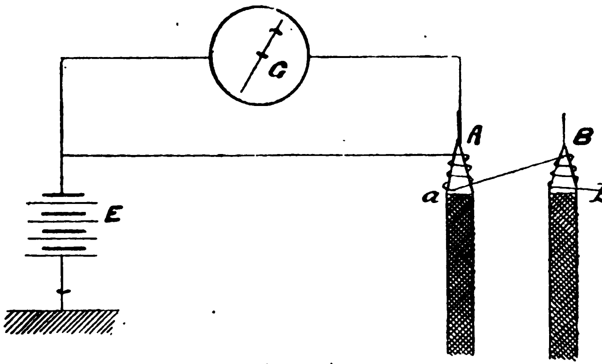


Fig. 87.

of that bugbear surface leakage, in insulation testing, etc. The principle, as applied to the extremities of a submerged cable under test for insulation, is represented in Fig. 87, where A and B represent the two extremities of the cable, duly prepared and tapered in the manner described under the heading of *Insulation Resistance Measurement*, G the galvanometer, and E the testing battery. At the points *a* and *b* a fine copper wire is wound tightly for some three or four turns around the tapered extremity of the insulation, over which the surface leakage tends to take place, and connected, as shown, between the galvanometer and battery. However great the leakage tendency before this precaution was taken, it will be found to have entirely disappeared when the connections are arranged as in the figure, and only the true deflection due to the cable will be obtained.

The same principle may be applied to prevent surface leakage on the galvanometer by connecting the three levelling screws or case of the latter to the insulated battery terminal, care being taken to ensure the thorough insulation in all other respects of the galvanometer itself, as otherwise a short circuit will exist across the battery terminals.

Output of a Battery when Working.—This ingenious method was devised by Mr. I. Probert, and is specially applicable to the measurement of the discharge current from a small battery or accumulator such as those employed for the lighting of miniature incandescent lamps, etc., where the resistance of an ammeter, however low, if placed directly in circuit, would cause an appreciable reduction in the amount of current passing. The method is illustrated in Fig. 88, where E is the battery under

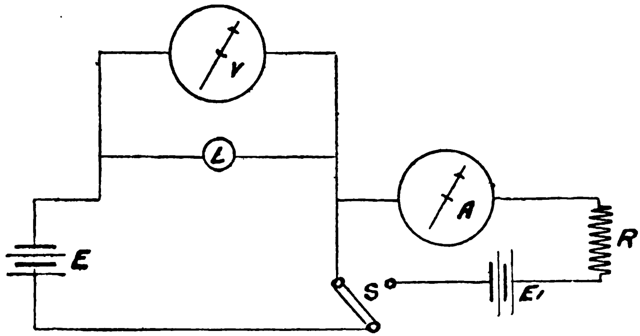


FIG. 88.

test, which, in the position shown, of the two-way switch S normally supplies current to the lamp L. V is a voltmeter of high resistance placed across the terminals of the latter. E1 is an auxiliary battery, A an ammeter, and R a liquid resistance, capable of minute adjustment. The method of conducting the test is as follows:—The reading on the voltmeter V is noted under the normal conditions depicted above, and S is then switched over such that the auxiliary battery E1, resistance R, and ammeter A, are introduced into the circuit.

R is then adjusted until the original reading on V is reproduced; the ammeter A will then record the normal current taken by the lamp.

A Method of Measuring the Resistance of an Electric Lamp whilst in a State of Incandescence.—The following method, detailed by Kempe, is a very handy one for dealing with the required resistance of a lamp, or series of lamps, without interrupting the supply cur-

rent. It is represented diagrammatically in Fig. 89, where L represents the lamp under test, which is lit by a current passing from A to B as indicated by the arrow heads. R is a resistance of suitable value connected in series with it. The E.M.F. between the extremities of

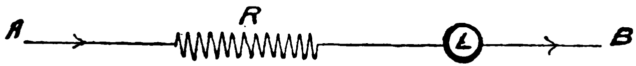


FIG. 89.

R is measured; we will call it E; likewise the E.M.F. at the terminals of the lamp, which we will call El. Then the required resistance x of the lamp L: $x = R\,\frac{El}{E}$

Having thus ascertained the resistance of the lamp, the current consumed by it can easily be determined by a simple application of Ohm's law, for the required current $C = \frac{El}{R}$

Test for Differentiality.—To ascertain whether a galvanometer be truly differential, its coils should be connected up in series in such a manner that the deflective effects of the currents in the two windings oppose one another, and a current passed through them. If there be any deflection, however slight, it indicates that the instrument is not truly differential, and that the deflective effect of one coil or set of coils is slightly in excess of that due to the other. If, on the other hand, no deflection be obtained with the coils or windings thus connected, they may be again arranged, in parallel, but still opposing one another, and the experiment repeated; if no deflection result, the resistances of the opposing windings are equal to one another.

To correct an error discovered by the above test additional resistance must be connected in series with one of the windings, and such resistance should preferably be of the same material and gauge as the actual winding itself, and located on the same base with the galvanometer, in order that its temperature coefficient and deflective effect (if any) on the moving system of the in-

strument may be synonymous with that of the instrument itself.

Resistance of a Partial Earth Fault.—A rough method for the determiration of fault resistance by the aid of a high resistance voltmeter is due to Swinburne, and consists in first measuring the testing voltage by means of the said voltmeter connected across its terminals, and then obtaining a second, lesser reading from the voltmeter in series with the fault, then—

$$\frac{\text{Direct Reading}}{\text{Leak Reading}} = \frac{\text{Resistance of Leak} + \text{Resistance of Voltmeter}}{\text{Resistance of Voltmeter}}$$

Ammeter and Voltmeter Calibration.—This series would not be complete without a more or less detailed reference to the subject of calibration, or, in other words, the comparison of a commercial instrument with a standard, for the purpose of preparing a scale for, or correct system of, reading the indications of the former. The usual plan adopted in factories where commercial instruments are constructed consists in first standardising one individual instrument by one of the methods to be described, and then adopting it as a standard of comparison with the remainder, checking it from time to time by the original method, as circumstances and previous experience dictate. I will now proceed to deal with one or two methods for calibration of the commercial standards, involving the use of simple apparatus, and, as an opening, we will consider the all-important section included under the heading of *Voltmeters*.

For voltmeter calibration we require a source of E.M.F. capable of supplying a voltage at least equal to the maximum reading on the scale of the instrument under calibration, and this is best supplied by a battery of accumulators. If an ordinary current-yielding set of accumulators be not obtainable, the requirement may be met by one of the many patterns of testing battery on the market, most of which consist of a pair of lead strips, pasted or "formed" in the usual manner, and immersed in an electrolyte contained in a small test tube. If such a set be adopted for the purpose in hand, it must be borne in mind that no appreciable current can

be taken from them without materially lowering the terminal voltage, and, to this end, it is usual to employ them in opposition to the standard testing voltage which is commonly provided by a standard cell or cells.

A simple method of voltmeter calibration, described by Swinburne, and adopted, I believe, by Messrs. Crompton and Co. in the earlier days of instrument manufacture, is depicted in Fig. 90, where *a*, *b*, and *c* represent, as usual, the proportional and adjustable arms respectively of a Post Office Wheatstone bridge. V is the voltmeter to be calibrated, E the source of E.M.F. previously alluded to, Es a standard cell (usually Clark's). K2 is an auxiliary circuit key, R an adjustable resistance arranged in convenient form, so as to give a wide range of adjustment, *r* being an auxiliary rheostat or slide resistance for final balancing in reading to single degrees of the voltmeter scale. *r*1 and *r*2 are special resistances of 54.6 and 145.4 B.A. ohms respectively, introduced in order to render the arrangement direct reading in B.A. volts, their total resistance being 200 B.A. ohms.

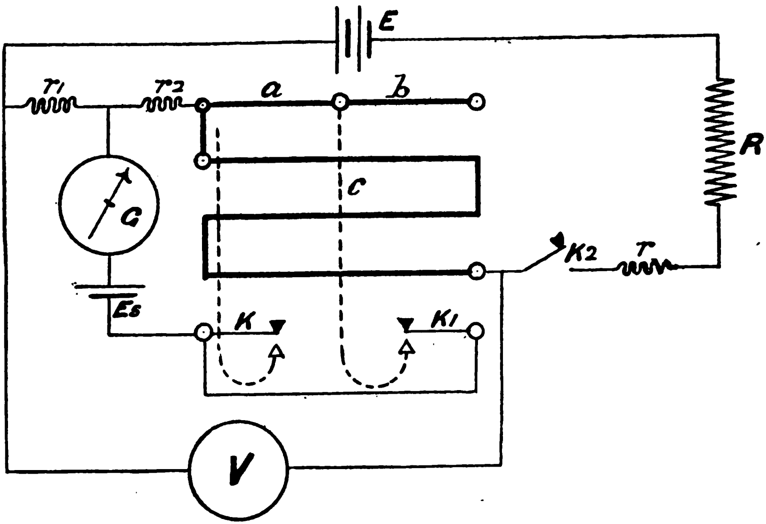


Fig. 90.

In the event of standards other than B.A. being adopted, the same sum of resistances must be adhered to. G is a galvanometer.

As to the actual manner of conducting the operation, I cannot do better than quote Mr. Swinburne's own remarks on the subject:—

"R, *r*, in Fig. 90, are adjustable resistances and rheostat coupled up as shown. This resistance box is supposed to have coils for the thousands, so that when all the plugs are out 11,110 ohms are in circuit; *r*1 and *r*2 are two specially made up resistances of 54.6 and 145.4 ohms respectively. The Clark standard cell is in series with a galvanometer G. The standard cell circuit is from between *r*1 and *r*2 to the keys, so as to shunt the resistance of 145.4 ohms. If the plugs be withdrawn between the extremities of arm *a*, there is a resistance of 1,110 ohms in the standard cell circuit. The object of the resistance *r*1 is to make up 200 ohms with *r*2, so that the apparatus may be direct reading.

"Suppose the voltmeter is to be calibrated up to 100 volts. To get 50 volts on it, plugs are drawn in the resistance box to give 4,800 ohms, which, with *r*1 and *r*2, make up 5,000 ohms. The resistances R are then adjusted till approximately 50 volts are on the voltmeter. The key K1 is then pressed for a moment. The galvanometer will be deflected, showing that there is too much or too little electromotive force. The switches R can regulate within 1 per cent., so that a pair of positions will be found, one on each side of the desired resistance. The rheostat *r* is then adjusted till there is no deflection on pressing K1. The key K is then pressed, and a final adjustment made. The key K1 and its resistances are put to prevent a large current passing through the cell in either direction, and the key K must only be used for final adjustment. The 50-volt reading having been taken, 5,100 ohms are drawn, and the 51-volt reading is taken, and so on."

An alternative method, which, however, possesses the attendant disadvantages that it is not direct reading, and that it cannot be adopted except in the case of high resistance voltmeters, the maximum current through the coils of which will not be sufficient to appreciably heat the bridge coils, is represented in Fig. 91, and is based

upon Ohm's familiar law, E equals C.R. In this method, the resistance of the voltmeter is first measured by one of the ordinary methods at its normal temperature, *i.e.*, at that temperature which its winding will have when connected across an electromotive force equal to that which it is ultimately intended to measure. This resistance having been duly obtained and noted, attention must be given to Fig. 91, in which the same lettering is used as in the previous figure. It will be seen on reference to this figure that the voltmeter V, testing E.M.F., E., and resistances R, *r*, are connected in series with the bridge, whilst the standard cell Es and galvanometer G are in shunt.

The method of conducting the test in this case consists in inserting resistances in the bridge, and adjusting R and *r* until there is no deflection on the galvanometer G, then, by Ohm's law, the current will be equal to the E.M.F. of the standard cell Es, divided by the resistance as read on the bridge coils. The value for C thus obtained, multiplied by the previously measured voltmeter resistance, gives the true reading of the voltmeter V at the time.

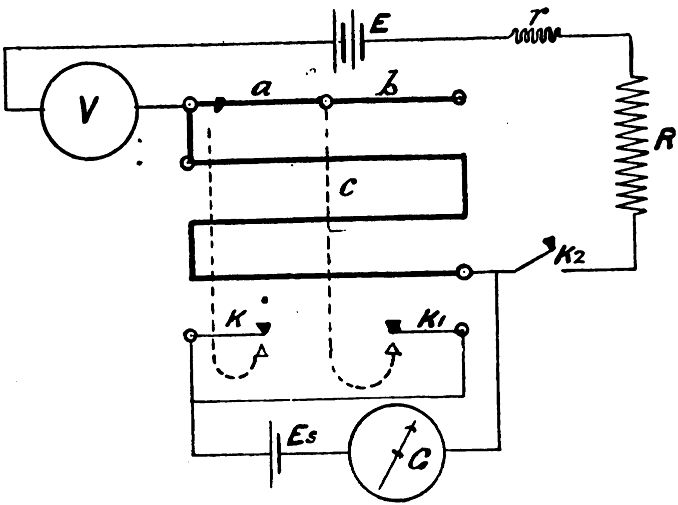


Fig. 91.

A somewhat rougher method of voltmeter calibration by the aid of a metre bridge is represented in Fig. 92, where A B is the homogeneous slide wire of an ordinary metre bridge, the resistance of which, per unit of length, must be known. R is an adjustable resistance of such a type that it will not appreciably heat with the current passing through it under the maximum E.M.F. to be recorded on the voltmeter V. E is the testing battery, as

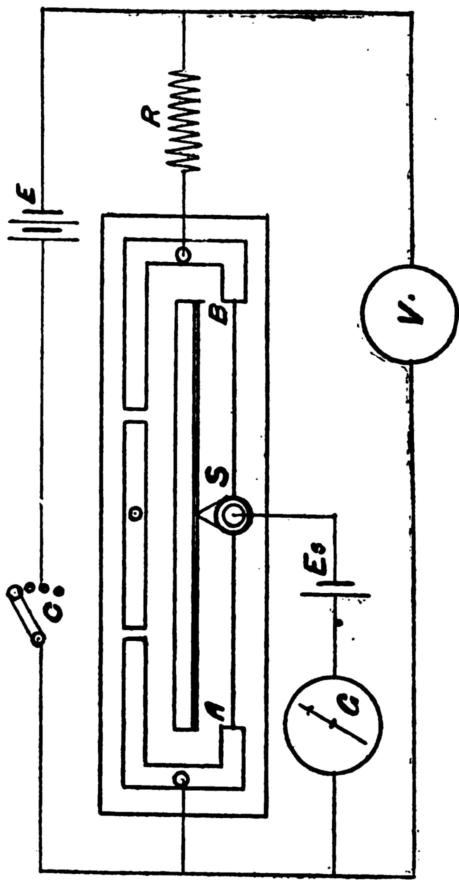


Fig. 92.

before, fitted with a multiple contact switch C, by which the number of cells in circuit, and consequently the terminal voltage, can be varied at will. Es is the standard cell, and G the shunted galvanometer arranged in derived circuit as shown, one connection being adjustable as to its point of contact with the wire A B, by means of the slider S.

The *modus operandi* is as follows:—A given number of cells of the battery E, approximately yielding an E.M.F. equal to one of the required readings on V, are switched in circuit, and, by means of R, the resultant deflection on G is so regulated that the slider S is on or about the centre of the scale. S is then adjusted until a balance is obtained on G, a final adjustment being made with the shunt removed; then E.M.F. recorded on

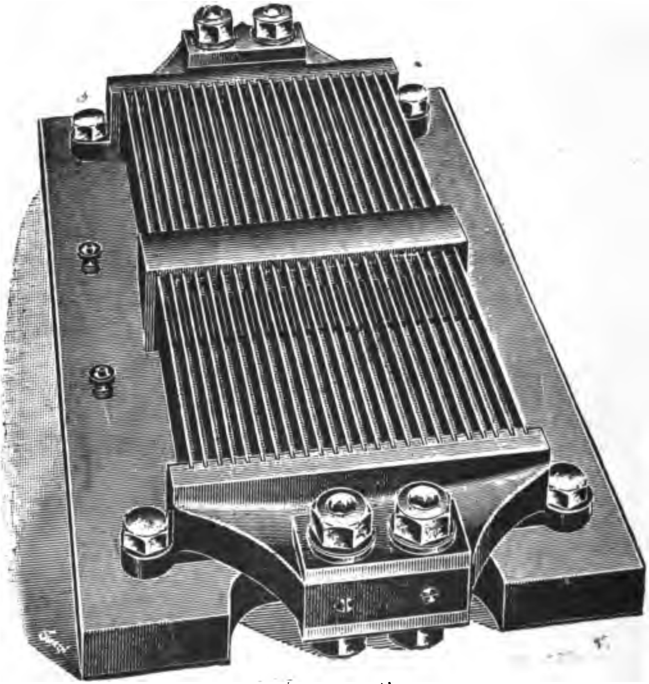
$$V = \frac{\text{E.M.F. of standard cell (resistance A B R)}}{\text{resistance A S.}}$$

Ammeters.—These instruments are usually calibrated commercially, like voltmeters, by comparison with a standard instrument. For the accurate calibration of the original standard two systems are available, one of which, essentially a laboratory method and requiring the employment of delicate apparatus, is by voltameter, and the second, with which we will now proceed to deal, is by standard cell and calibrated resistance.

Professor Fleming's method of ammeter calibration by this system consists in the following:—A series of resistances are constructed, of convenient dimensions, and their actual resistances and conductivities carefully measured and noted. They are fitted with an arrangement of mercury cups so that they may be connected in parallel or in series at will. A certain number of them are then arranged in multiple such that they will permit the passage of a certain current within the range of the instrument to be calibrated, under a convenient difference of potential. This E.M.F. is measured by the standard cell and slide wire or potentiometer method, and the actual current passing is then calculated by Ohm's law. In the event of any heating of the resistances they are at once connected in series, and their resistance measured. The number of resistances is then altered,

and a second reading obtained, and so on throughout the range of the ammeter scale.

A very cute and practical method of ammeter calibration was devised some years back by Mr. Evershed, and consists in first constructing, with the utmost care, a



STANDARD RESISTANCE FOR HEAVY CURRENTS, BY ELLIOTT BROS.

standard instrument to indicate exactly one ampère. This is connected in series with the ammeter to be calibrated and a convenient resistance and source of current. Several other resistances exactly equal to that of the standard instrument are constructed, and, by connecting them in parallel with it, the calibrating current can be varied ampère by ampère throughout the range of the scale.

All methods of ammeter calibration by the aid of a standard cell and resistance are based on Ohm's law, $C = \frac{E}{R}$, and, to this end, the resistances employed require to be very accurately constructed and calibrated, if any degree of accuracy in the ultimate calibration is to be attained. Messrs. Elliott Bros. manufacture a series of standard resistances to carry heavy currents, of which the accompanying illustration is typical. They are so constructed that the temperature and consequent resistance error on the passage of the maximum current specified shall not exceed 0.25 per cent.

For roughly checking an ammeter, a home-made resistance of the above type may be conveniently constructed by selecting, say, 10 ohms of German silver or platinoid wire of convenient current-carrying capacity, and cutting it up into ten equal lengths, which should have a resistance of 1 ohm each. If these be then carefully soldered across two massive copper bars, a very convenient resistance of 0.1 ohm is the result. Other values may be constructed in like manner, care being taken to allow a slight margin for the actual soldering, which should be kept within that margin.

In the various calibration methods for voltmeters and ammeters enumerated above, too much stress cannot be laid upon the subject of insulation, which should be as perfect as possible in the case of all and every piece of apparatus used, especially the batteries, or serious errors will creep into the results.

The tangent galvanometer is principally employed in the system of daily tests for insulation on all their telegraph circuits and lines, as instituted by the G.P.O. The system was devised by Mr. A. Eden, and is illustrated by Fig. 93, where G represents the P.O. tangent galvanometer, with its coils arranged differentially, E the testing battery, and r, $r1$ two equal resistances of 10,000 ohms introduced between the extremities of the two line terminals and the galvanometer G. The lines are looped at their distant extremities as shown.

The *modus operandi* is as follows:—One winding of the galvanometer G is first connected with a low resistance battery through a standard resistance of 20,000 ohms, and the battery voltage is regulated until a con-

stant deflection of approximately 110 tangent divisions is obtained on its scale. The constant having been thus obtained and noted, the galvanometer is next connected as shown in Fig. 93, such that the current from the bat-

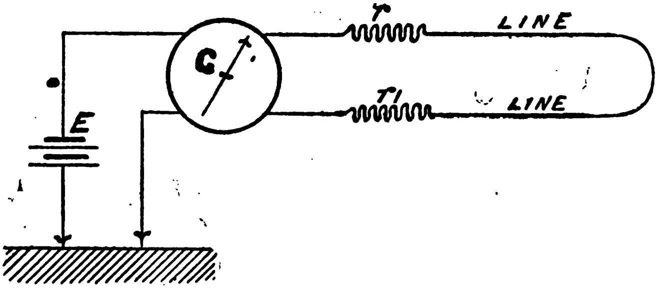


FIG. 93.

tery E will tend, by flowing through both windings, to produce a deflection in opposite directions of the galvanometer needle. It is obvious, then, that if the insulation resistance of the line be infinite, and there be no leakage, the currents through r and $r1$, and consequently through the two sides of the galvanometer winding, will be equal and opposite, and, as a natural consequence, no deflection will result; if, on the other hand, there be a leakage, either local or general, at any point on either side of the lines, the current through r will be greater than that through $r1$, and a deflection will result. By means of a series of specially prepared tables, this deflection can be rendered in terms of the insulation resistance of the line, in "megohms per mile." The conductor resistance of the loop naturally enters into these calculations, and is duly provided for in the tables alluded to.

In the event of a single line requiring a test where no looping can be effected, the distant end is put to earth through a combined resistance of 10,000 ohms, and the winding of the galvanometer normally connected to $r1$, and the deflection due to the line, as calculated for perfect insulation, is deducted from the observed deflection, then the remainder, multiplied by 2, will give the required deflection from which the insulation resistance can be deduced, as before, by reference to the tables.

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